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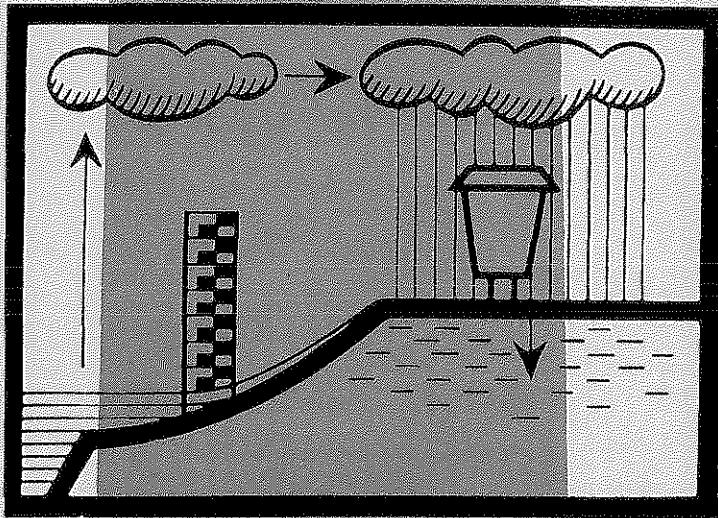
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**MORPHOLOGY AND MORPHOMETRY
OF A CHANNELIZED STREAM:
THE CASE HISTORY OF BIG PINE CREEK DITCH,
BENTON COUNTY, INDIANA**
Studies in Fluvial Geomorphology No. 4

by

Robert S. Barnard

JUNE 1977



**PURDUE UNIVERSITY
WATER RESOURCES RESEARCH CENTER
WEST LAFAYETTE, INDIANA**

MORPHOLOGY AND MORPHOMETRY OF A CHANNELIZED STREAM:
THE CASE HISTORY OF BIG PINE CREEK DITCH, BENTON COUNTY, INDIANA

by

Robert S. Barnard

This is a partial completion report for
OWRT Project No. A-035-IND (Agreement No. 14-34-0001-6015)
entitled "Channel Morphology, Stream Power, and Sediment
Types as Related to Channelization and River Training"

Purdue University
Department of Geosciences
West Lafayette, Indiana

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PREFACE

This report is the fourth in a numbered series of Studies in Fluvial Geomorphology prepared by the Geomorphology group at Purdue University under funding provided by OWRT and its predecessor, the Office of Water Resources Research. The investigation could not have been successfully conducted without the background of fundamental data and basic research provided by previous studies in the series, most specifically Technical Report 47 (Keller and Melhorn, 1974), and a study of the stream power concept in fluvial systems by D.E. Edgar, now in preparation for publication as Purdue WRRRC Technical Report 93. In our opinion, the results reported upon here clearly demonstrate that applications research in the real world of natural streams must be preceded by studies of their fundamental morphology and an understanding of the parameters of adjustment available in fluvial systems.

The present study, which was the basis for an M.S. thesis by Mr. Robert S. Barnard, was a natural outgrowth of experience and knowledge gained during the time he acted as a capable field assistant to Dr. Edgar in the stream power study cited in the preceding paragraph. The eventual objective of our continuing research has been to transmit and apply the knowledge gained to study of streams altered by the works of man, for such streams characterize, even dominate, in agricultural and urban areas of the United States.

The selection of Big Pine Creek Ditch in Benton County, Indiana as an initial test case, was indeed a fortunate choice. Historical data were available to reconstruct a relatively accurate pattern for the stream prior to channelization in 1932. Original engineering design and plans for channel "improvements" were still available as public documents. Topographic maps and sequential air photography provided intermediate reference points. After generalized mapping of the present channel morphology, and detailed field mapping in a few reaches where major changes have occurred since channelization and no maintenance measures have been performed, it was possible to predict, or at least speculate with some degree of confidence, future changes that would occur as the stream slowly reverts or recovers to its natural state.

There are few reports in published literature that attempt such an historical analysis of the fate of dammed or channelized waterways. We hope that this study will interest other researchers in pursuing similar investigations of altered streams in differing geographic and physiographic settings. Such inputs, if the results are widely disseminated to agencies and institutions involved in construction or maintenance of artificial channels, should help in eventually leading to better design and controls wherein natural and aesthetic qualities of streams can be left intact, yet still provide adequate drainage of agricultural lands and protection from floods.

Wilton N. Melhorn
Principal Investigator

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ABSTRACT

Stream channelization involves straightening of a stream, either by enlarging and deepening the existing channel, or by dredging a new channel into which the stream is diverted. These techniques have been used for many years by Federal authority and state and local soil-water conservation district agencies for the purposes of flood control, improved navigation, and better drainage of urban and agricultural areas. The act of channelization results in dislocations of the fluvial regime which are very much in opposition to the dynamics of natural stream flow. Streams tend to maintain a certain channel form, sinuosity, slope, and load characteristic, so that when one of these parameters is altered, the open thermodynamic system tends to adjust other parameters to regain a quasi-equilibrium state. Thus the change from a sluggish, meandering stream to a much straighter one with a steeper profile will cause an adjustment towards the stream's more natural state. In this adjustment process, drainage basin and channel instability, bank erosion and deteriorating environmental quality are commonplace, thus making channelization an unsatisfactory solution.

Big Pine Creek Ditch, in Benton Co., Indiana, was channelized in 1932 to provide improved drainage of adjacent farmland. Subsequent changes in channel form and slope have caused considerable lateral migration, and scour and fill at various points along the seven-mile channelized reach. A study of this test stream has included an assessment of cross-sectional and morphometric deterioration, as meander development and profile adjustments have considerably reduced the channel's drainage capacity.

Attempts to determine the cause of deterioration have included investigation of change in material type, distribution of spoil materials, and variations of channel slope and stream power. Relationships between stream power and sinuosity seem to be the most significant and a stability envelope is developed for the prechannelized, natural stream. The same relationship in 1938, 1963, and 1971 indicates instability and a trend towards more natural conditions. This trending relationship is also used to predict recovery rates and amounts of recovery with time.

Definition of these relationships has allowed the recognition of design errors, and permits suggestions as to methods of correction and new designs for drainage improvement. The use of new concepts and designs should lead to the construction of more stable channels.

INTRODUCTION

The practice of channelizing rivers and streams consists of deepening, widening, straightening, cleaning or lining existing channels. Channelization is not in itself the ultimate objective in such projects, but is merely the methodology used in attempting to achieve more important goals, such as flood control, better drainage, or improved navigation. Although such goals may indeed be desirable, channelization often creates additional problems, especially in terms of stream instability and environmental degradation.

The reclamation of vast wetlands in the nation's central states has been accomplished historically by increasing the drainage capacity of many miles of headwater streams, which was possible only by channelization. Although agricultural production has been increased (and in some areas, literally, made possible for the first time) by channel modification, new problems such as declining water tables and flooding in downstream reaches have been created. Floodways and reservoirs generally require more land than do channel modifications, so in many areas channelization has been the cheapest economic method available to reduce the danger of damaging floods. Increased stream capacities and reduced obstruction to flow are instrumental in lowering flood

stages. However, commonly only certain reaches obtain the required attention, thus creating greater flooding downstream. Many miles of the nation's inland waterways are navigable only because the rivers have been deepened, widened, and straightened. All too often such measures create unstable conditions in streamflow, causing considerable channel scour and fill, which thus necessitates frequent maintenance or additional "channel improvements".

Channelization usually entails some modification of the physical properties of the stream bed and banks, regulation of natural streamflow parameters, and alteration of flood plain geometry. Such practices can transform naturally adjusted hydrologic and ecologic systems into a chaotic, unharmonious disarray of streamflow, vegetation and wildlife. Plant and/or animal life may be exterminated or unwittingly displaced, and complete instability may replace the established streamflow equilibrium. Some channel modification projects are successful in increasing an areas' worth, whereas others seem to be a traumatic assault on free-flowing water bodies whose natural resources or aesthetic values are often irreplaceable in a particular region. Channelization per se is not evil, but the inadequate advance consideration of adverse environmental effects produced by such projects is assuredly bad.

The need for channelization normally arises as a result of man's activities. Increased agricultural activity in rural areas and construction in urban areas tends to increase

runoff and also sediment load. Exposure of erodable material in agricultural and urban areas can increase sediment yields 5 to 700 times normal levels (Wolman and Schick, 1967). Installation of tile drains or storm sewers and creation of large areas of impermeable surface (urbanization) will soon create a stream choked with sediment and overloaded with runoff of greater intensity, causing higher frequency of overbank flow.

Although much discussion has been devoted to the detrimental effects of channelization, the need for this type of modification is likely to continue. Improved drainage in abnormally wet farmlands can increase productivity immensely. The realignment of stream flow across highways may cut the cost of bridge design by thousands of dollars. Elimination of a tortuous river course could reduce considerably the problems and cost of navigation. Therefore, it seems useful to develop new methods to reduce environmental degradation and the need for continual maintenance, and to include these factors in initial planning and design of new channelization projects.

Current engineering designs in channelization are progressing away from the straight, box-like trapezoidal or rectangular channels with uniform gradients formerly used, and are moving towards retaining more naturally appearing and functioning streams (Keller, 1976). The recent development of concern in this country for the environment has exerted pressure to continue this trend, especially as the prepara-

tion of environmental impact statements now is required on any project subsidized by Federal funding. The future will see a continuation of similar policies, and possibly more stringent regulations will be placed on such projects. New ideas and designs will be needed to accomplish intended objectives, meanwhile concurrently protecting or enhancing the environment.

PURPOSE and SCOPE

The purpose of this report is to increase the understanding about the nature of fluvial response to channelization. Very few quantitative case studies have traced the historical or sequential development of a streams' post-channelization readjustments. Therefore, little is known about stream channel and drainage basin response to such modifications, but meanwhile many miles of waterway continue to be modified each year. A better understanding of the effects of channelization, as provided by case studies, not only may help to correct some design errors from past projects, but also may provide some clues that will help create more efficient, more stable channels.

This report includes: 1) A review of the history of channelization, methods used, general results and results of other specific case studies, and environmental impact on stream biota and wildlife; 2) a historical analysis of Big Pine Creek Ditch in Benton County, Indiana, including morphometric and morphologic changes in stream parameters since

channelization, and a general analysis of the apparent trend towards readjustment back to pre-channelized conditions; 3) investigations of new designs and concepts, such as the application of ideas about fluvial thresholds, which if utilized might promote greater stability in channelized streams.

THE HISTORY of MIDWESTERN CHANNELIZATION

Channelization in the United States began well over 150 years ago with the westward movement of settlers. As the need for food in the cities increased, so did the need for productive farmlands. In the Midwestern states, early settlers found wide, flat to gently rolling, swampy expanses covered with tall prairie grasses, bluestem and sloughgrass. There was little natural surface drainage, and much of this swamp land underlain by rich, black, clay loam soil was considered worthless. Early attempts at farming these lands resulted in failures, and mosquito-infested swamps commonly led to epidemics of malaria and spotted fever (Hay and Stall, 1974).

Initial attempts to construct drainage channels were slow, crude, and ineffective. Teams of horses or oxen pulling slip scrapers and gigantic ditching plows, followed by men with shovels, opened many shallow ditches. The products were at best only partially effective, and commonly created new problems with drainage further downstream (Hay and Stall, 1974).

As techniques improved, ditching plows were replaced by draglines and floating dredge boats, but the nature of channelization projects was unorganized and quite disjointed. Although problems of individual areas may have been resolved, little or no consideration was given to dislocations of the fluvial regime downstream or to more wide-spread environmental disturbances. Establishment of regional and local soil-water conservation and planning agencies in recent decades has helped eliminate some confusion by including an entire basin in project design and objectives. Even now, however, lack of funding and inadequate planning often limits design and construction to completion of an ineffective drainage project encompassing only a part of a drainage basin.

CHANNELIZATION METHODS

Through the years, many channel improvement methods have been used, the type depending upon the desired goal. Of course, not all projects have the same objectives, nor will the areal physical characteristics allow use of identical construction techniques. Projects often include one or more of the following list of popular methods.

1. Widening, deepening and straightening is one of the most common techniques associated with channelization. This involves the near total physical alteration of stream bed and bank characteristics, and channel location. An increase in stream capacity and slope theoretically increases stream

velocity and discharge, and thus the celerity with which the stream will drain. As this method involves the most complete transformation from natural conditions, it can be expected to result in the greatest disruption of equilibrium conditions of stream flow and wildlife ecology.

2. Clearing and snagging involves removal of brush, logs, and other flow obstructions in the channel and on adjacent banks, and commonly includes concurrent removal of sand and silt deposits from the channel. Normally, no channel enlargement is included, but added velocity resulting from removal of obstructions increases channel discharge capacity. In attempting to minimize ecosystem disruption, the Soil Conservation Service has often confined clearing to only one bank, leaving the other bank as undisturbed as possible. The concept is good in theory, but in practice the success of this method has been limited in retaining unaltered conditions.

3. Diking involves construction of artificial levees, increasing bank height on one or both sides, thus increasing capacity and raising the height of bankfull stage. This technique is normally used to protect urban and agricultural areas from damage by flooding.

4. Bank stabilization is often incorporated along with one or more of the other methods, and normally entails reinforcement of erosion-prone areas of bank and channel with rip-rap or hearty taprooted grasses. This method commonly

involves decreasing bank slope or loading slope toes with resistant material (rip-rap).

5. Lining of the channel with concrete, etc., is the ultimate in stabilization, but this does not allow existence of any stream or bank biota, and of course removes all semblance of natural conditions.

RESULTS of CHANNELIZATION: CASE STUDIES

Regardless of the method used in channel modification projects, there will be some degree of readjustment involved in stream flow and ecology. Some projects have produced more drastic readjustments than others, and have resulted in considerable damage in the process. Several rather well documented cases of such readjustments are reported herein, in order to provide some measure of the magnitude of damage.

Blackwater River

In 1910, the newly created drainage district authority in Johnson County, Missouri, shortened a 33 mile stretch of the Blackwater River by almost 18 miles. The pre-channelized stream contained 2.9 meanders/mi with radii of 180 to 420 feet, had an average gradient of 8.8 ft/mi, and a channel width of 15 to 20 feet. The ditch was 18 feet wide from bank to bank, had a bottom width of three feet, and was 12 feet deep. Stream gradients thus were increased to more than 16 ft/mi (Emerson, 1971).

Since channelization, scour and fill have been the dominant forms of readjustment, with an average of three ft/yr of lateral erosion and nearly 0.5 feet of downcutting/yr. This has caused an increase of more than 1000 percent in channel cross-sectional area in some reaches within a 60 year period.

Bed conditions, cut in soft Pennsylvanian limestone, sandstone and shales have resulted in chute-like conditions that have reduced fish populations to less than 20 percent of that estimated before channelization. Tributaries have entrenched an average of 12 feet, causing destruction of farmland and highway bridges. Local residents state that no extensive flooding occurred before channel improvements, but since then, nearly six feet of material has been deposited on the adjacent flood plain. The effectiveness of the river's lower reaches has been greatly reduced by channel deposition, a condition that continues to progress upstream. The project has allowed more agricultural use of the flood plain in the river's upper reaches, but this benefit has been far outweighed by destruction of farmland and highway bridges downstream. (Emerson, 1971)

Peabody River

During periods of flooding in 1959 the Peabody River in New Hampshire undermined and partly collapsed a section of New Hampshire Route 16. Economics of reconstruction dictated a channel relocation as prevention of further flood damage

to the road, and in 1961 the channel was straightened and shortened 850 feet. Channel gradients were changed from an original 52 ft/mi to 80 ft/mi.

Subsequently, in an attempt to regain a more natural gradient, the stream alternately scoured and filled its bed, thus reducing the gradient to 75 ft/mi after two years, and 70 ft/mi after seven years. Considerable vertical and lateral scour accompanied the readjustment, with as much as 18 feet of vertical scour within the reach immediately upstream of the channelized segment, and channel width increases as great as three to four times the original channel dimensions (Yearke, 1971).

Willow River

The Willow River in Harrison and Monona Counties, Iowa, also frequently flooded its valley to a depth of several feet, and the area was generally considered unfit for cultivation. To alleviate this condition, the stream was modified in stages, beginning in 1906 and finally completed in 1920. The upper reaches were constructed with a 12 foot wide base and 1:1 side slopes; the lower reaches with an 18 foot wide base and 1:1 side slopes. Gradients were changed from as much as 7.5 ft/mi, to as much as 12.2 ft/mi.

Since construction, the lower reaches (which are located in the Missouri River valley) have undergone considerable siltation. Locally the bottom of the channel has filled to a level above that of the tile drain outlets. This portion

of the ditch was cleaned out in 1916 and again in 1941. The upper portion of the ditch has entrenched and assumed a distinctive U-shaped cross-section, in contrast to the trapezoidal shape of the original channel. As might be expected, a series of knickpoints also have formed and have migrated upstream as much as 0.5 mi/yr in both the main stream and its tributaries.

The original objective of the project has been achieved in the upper reaches of the Willow River, but not without secondary complications. Flooding in the upper portions has not occurred since 1942 owing to entrenchment and widening of the channel. However, lower reaches of the river have needed repeated remedial measures to retain the necessary channel capacity. In this case it appears that insufficient consideration of and knowledge about the latent effects of channelization, has produced a potentially degenerative and expensive drainage project (Daniels, 1960).

ENVIRONMENTAL IMPACT

As is quite evident from the preceding case studies, channelization can result in considerable alteration of the stream's natural regime. These alterations can effect channel and flood plain stability in both upstream and downstream reaches, stream biota and wildlife, and general aesthetic appeal.

Streams can be considered as open thermodynamic systems in which there are numerous parameters that interact to pro-

duce a near equilibrium condition. These parameters, such as channel morphology (cross-section, sinuosity, pool-riffle development), slope, discharge, and sediment load, are constantly changing in nature. As one parameter is altered by some agent of change in the open system, the stream immediately adjusts other factors to regain its quasi-equilibrium, or more natural state.

Although the natural stream's channel form and the processes acting upon it evolve in harmony, man has not been able to achieve comparable results, because consideration of fluvial operational processes is often totally ignored. Channelization projects have too often produced disastrous results because engineering design is not compatible with requirements of the natural stream state.

Impact on Channel and Flood Plain

Channelization, if incorporating straightening or deepening procedures, can be responsible for considerable bank erosion and channel entrenchment. Lateral erosion in some cases will initiate meander development whereas in other situations channel cross-sectional area may be increased immensely. Either case will infringe upon the very land that was to be protected by the channelization project, and may even cause the undermining or destruction of highways and bridges.

Straightening and deepening will also alter the natural channel gradient established over many years. Any existing pools and riffles will be destroyed, and it may take many

years to reestablish a stable pool-riffle sequence. Deepening will also effectively lower local base level which may affect, to a great degree, water levels in tributary streams. As noted by Daniels (1960), entrenchment from channel gradient readjustment caused severe scour and headward erosion in tributary streams, and knickpoint development on the main trunk stream of Willow River in Iowa.

Any increased erosion in upstream reaches will also cause increased deposition at some point downstream. With constant or increasing channel widths downstream, any decrease in gradient will slow the flow and thus cause deposition of part or all of the stream's load. Continued deposition will soon produce a filled channel, with little or no capacity to accommodate flood discharges comparable to design criteria. This situation will then necessitate remedial maintenance, at constantly inflated costs.

To assert that channelization causes flooding in downstream reaches is a gross and unwarranted generalization. In many cases increased deposition is the cause of downstream flooding. In other cases discharge from the channelized tributaries tends to overwhelm and exceed the capacity of the unimproved mainstream. Channelization often reduces such flood hazards by moving the flood peak out of the basin prior to peaks arriving from other natural tributaries. Increased capacity in downstream reaches will also decrease flood peaks upstream and within the channelized reaches.

It should be noted that every stream and drainage basin is different, that is soils, bedrock, topography, and channel characteristics vary. A stream's response should be an important part of the planning of channel modification projects, with special consideration given to the erodability of channel and flood plain materials.

Impact on Wildlife

Channelization practices often transform a meandering stream with long, tranquil pools, and short active riffles, to one quite straight, nearly devoid of pools, but with numerous long riffles and much steeper gradients. Just as channel form evolves along with the processes acting upon it, stream biota adapt with change of channel form, and thus become well-adjusted with time. If all original life is not destroyed in the process of channelization, it soon may be, as biota may not be able to adjust to the new channel form or flow characteristics.

Fish and other stream life generally require a range of flow conditions that vary from slow, pool type environs, to swift, shallow, riffle conditions. During low-flow conditions, pools provide protection from both the heat of summer and the cold of winter. Breeding of many species must be accomplished in shallow riffles where the fry can find protection from predators in water plants and yet receive a supply of food from insect larvae and tiny crustaceans.

Removal of vegetation from stream banks may also create problems, as it may be used for cover during both high flow (high velocity) and low flow (provides insulation). Any type of channelization may effectively lower water table levels by increasing runoff, which decreases infiltration recharge to ground water storage. This in turn may cause reduced low flow levels, as less ground water may be available as effluent contribution to base flow in drier seasons. A decrease in low flow levels or base flow may allow summer temperatures of the open water to reach levels intolerable for many of the stream's plant and animal species.

Any increase in erosion in the basin may increase low water channel instability, deposition of mid-channel bars, and obstruction to flow. Shifting bedform configurations may eventually blanket bottom dwelling flora and fauna with sediment, and alter the stream environment by changing lighting characteristics and increasing the abrasive effects of the sediment load (Wolman and Schick, 1967).

Emerson (1971) attributes the reduction of fish populations in the Blackwater River to channelization. Nearby unchannelized streams average 550 pounds of fish per acre, whereas modified reaches of the river average only 120 pounds of fish per acre, even after 60 years of recovery. Other similar data are not available although it is anticipated that corresponding evidence would be obtained in many streams if studies were conducted.

Dale (1974) states that channelization reduces abundance as a result of habitat destruction and reduced food supply, and also reduces species diversification and shifts relative abundances among species. This commonly allows undesirable species to thrive and gain dominance in the community. So-called endangered or threatened species should also be considered as they are often the least resistant to changes in habitat. Amphibians and reptiles are also threatened by channelization practices, since they are dependent on damp or heavily shaded habitats and standing water for successful reproduction.

Similar effects may be expected with the flood plain's wildlife community. Larger prey species often are dependent on the stream for their food supply. More commonly, stream bank vegetation is essential for protection against predators, adverse weather, potential food supply and nesting grounds. Many animals are displaced during construction and return to find little or nothing of their original habitat remaining; possible overpopulation within undisturbed areas then leads to increased mortality and reduced numbers of these species.

Ecosystems are clearly as delicately balanced as the relations within the fluvial system, so that if one parametric condition is changed, many others necessarily will also change. Whether channelization disrupts one or many niches within the ecosystem, the food chain has been broken, and unless the community can adjust successfully, its total destruction is imminent.

Although it seems that some life will be destroyed by drainage projects, some species may benefit. Certain life forms are dependent on swift-flowing waters and channelization may also improve water quality to meet the requirements of these groups. Other species may thrive on early or transitional plant succession that may soon appear in cleared areas adjacent to improvement projects.

Aesthetic Degradation

The essence of aesthetic appeal of a stream lies in its proximity to the natural state. Removal of stream bank vegetation, pools, small waterfalls, rock outcrops, marshes and stream bends tends to destroy the natural aesthetic appeal inherent in the variety and contrast provided by pristine conditions. Removal of some or all contrasts provided by varying flow conditions, color variations inherent in changing vegetation types, and other features provided in nature tend to reduce the stream's aesthetic appeal.

Many channelization projects deal with streams already aesthetically unappealing, that is, filled to near capacity with sediment and debris and choked with vegetation that impedes flow and makes for near inaccessibility. In such cases, properly designed channelization projects may greatly improve the stream's aesthetic rating.

RECOVERY

Just as numerous variables must be considered in predicting stream response to channelization, these same variables effect the rate of recovery back towards natural conditions. Little is known about such recovery rates, as most channelized streams are not allowed to recover totally. Biologic recovery, if it is possible at all, will necessarily take longer than morphologic recovery of the stream. In most cases suitable habitats are dependent upon achievement of nearly stable morphologic conditions.

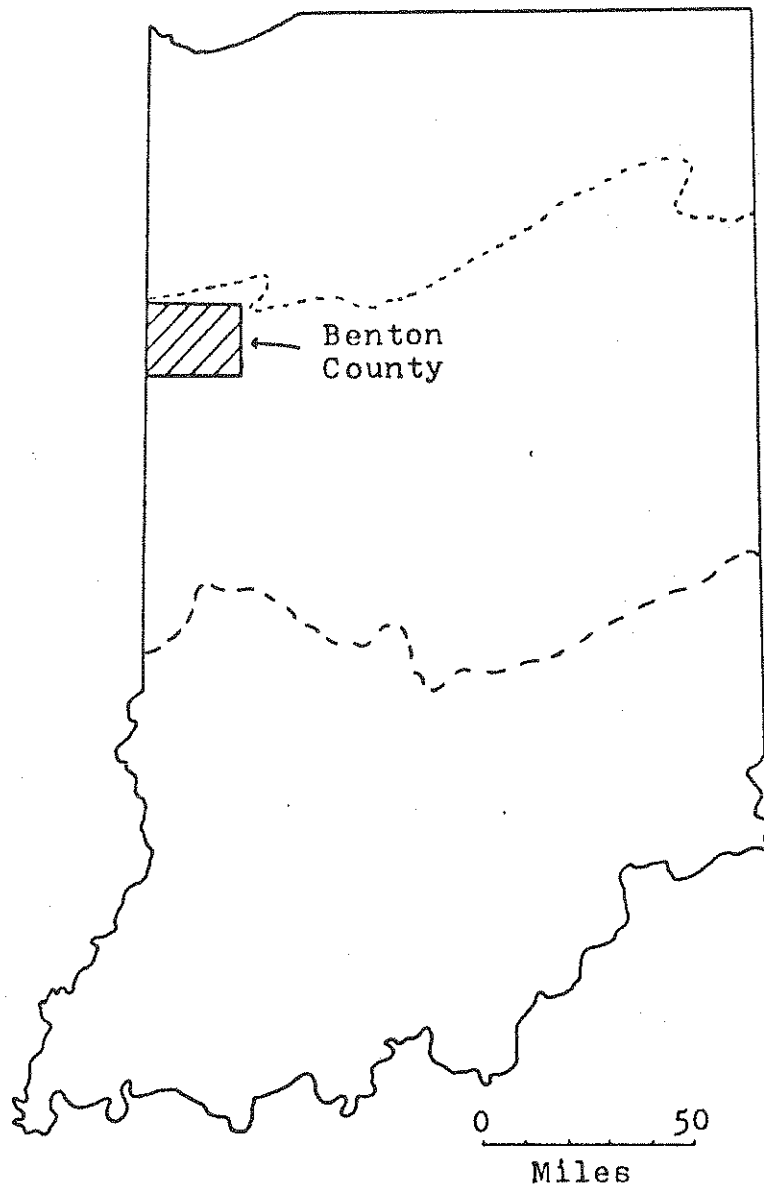
The return to more natural distribution of bed forms, such as pools and riffles, is likely to be fairly rapid as compared to total biological recovery. Although incipient pool-riffle sequences may form soon after channelization (Keller, 1975), these will tend to be rather unstable, and may take many more years before evolving to a truly stable state.

Recovery periods, in terms of years, can only be estimated from previous case studies of channelization projects. Emerson (1971) reports that after a 60 year recovery period, fish populations in the Blackwater River were not even close to levels of aquatic life in nearby streams, nor were morphologic parameters reaching any semblance of stable conditions. Big Pine Creek Ditch in Benton County, Indiana (the stream discussed in considerable detail later in the report), has undergone considerable morphologic readjustment since channelization in 1932; however, it appears presently

to be accelerating this adjustment in some reaches. Bed form evolution exhibits several stages of development, from incipient to near-stable pool-riffle sequences. Biologic recovery has been quite slow, as 40 years after channelization, the stream biota do not appear to even approach pre-channelized conditions. Local residents report that fish populations previously were of proportions to provide "keepers" to those who attempted to catch them, whereas species populations today remain reduced in number and diminished in size.

BIG PINE CREEK DITCH, BENTON COUNTY, INDIANA

Benton County is located in northwestern Indiana, approximately 65 miles south of Lake Michigan. The area lies within the Tipton Till Plain of Indiana, a flat Wisconsinan age plain comprised of glacial till and isolated areas of sand and gravel outwash deposits (see Figure 1). Elevations in the county range from 860 feet along parts of the Fowler Moraine, to a low of about 700 feet along the flood plain of Big Pine Creek, the county's major drainageway. Benton County is the headwater region of several major watersheds. The Nebo-Gilboa Ridge and the Fowler Moraine, end moraine-type features trending generally east-west across the county, act as watershed divides. Streams north of Mount Nebo and Mount Gilboa (possibly kames or large crevasse fillings) flow north, east, and west, and are tributary to the Iroquois and



----- Northern Boundary of the Tipton Till Plain
----- Southern Boundary of the Tipton Till Plain

Figure 1 Index map to the study area in Northwestern Indiana
and the relationship to the Tipton Till Plain.
(modified from Mallott, 1922)

Tippecanoe rivers. Those to the south, including Big Pine, Mud Pine and Mud creeks flow southward to the Wabash River.

The surface materials and soils are derived from glacial drift, water-laid outwash, and Recent alluvial and eolian deposits. Depth to bedrock varies considerably across the county, as preglacial topography was somewhat more rugged than it is today. Deeply incised preglacial valleys exist in the buried Devonian and Mississippian limestone and shales. One such valley follows the present course of Pine Creek along the county's eastern boundary, then crosses to the southwestern corner, where bedrock is estimated to be 400 feet below the surface. Bedrock exposure is confined to very few localities within the county, such as outcrops along Pine and Sugar creeks (Jones and Brill, 1917).

First settlements in the county were established along Pine Creek in the 1830's, and by 1845 the inhabitants had begun encroachment upon higher-level prairie lands where soils were wet but good for farming. Soon small, open ditches became common and were dug to aid in drainage of these wetlands; by 1875, installation of tile drains had begun in order to reclaim the wettest lands. Even into the early 1900's, the county's main streams and tributaries commonly flooded adjacent farmland during the spring season, and each year valuable top soil was being lost to flood flow.

Big Pine Creek Ditch heads in Section 24 (T26N, R8W), Union Township, and flows in a general easterly direction, draining the area between the Nebo-Gilboa Ridge and the

Fowler Moraine, emptying into Big Pine Creek in Section 1 (T25N, R7W), Pine Township. The drainage basin encompasses an area of 15.88 square miles, having a rather elongated basin shape (Watershed Shape Factor = 1.82) and a main stream length of 8.2 miles. Basin relief is 115 feet, from Mount Nebo to the outlet, and the basin drainage density is 3.56 mi/mi² (see Figure 2).

Only sparse information is available on the natural stream parameters and regimen before 1932. Prior to straightening, Pine Creek Tributary was a small stream that meandered extensively (sinuosity = 1.42) across a relatively wide flood plain. Meander wavelengths varied considerably, averaging 250 feet and ranging from 100 feet to 450 feet. Amplitudes ranged from 75 feet to 300 feet, averaging 150 feet.

Plate 1, showing the course of the pre-channelized Pine Creek Tributary, was prepared from aerial photography at a scale of 1:21,120, taken in 1938 by the USDA for the purpose of soil mapping. Since spoils from the channelization project were poorly distributed and not consistently used to fill the pre-existing channel, it was possible to map the original channel with considerable accuracy.

Figure 3 is a channel profile of the pre-channelized stream, prepared from elevations obtained from published USGS 7½' topographic maps (Mount Gilboa and Wadena, Indiana Quadrangles). After close examination and comparison of photography (1938) and maps (1962), it was possible to delineate meander scars and old channel patterns. Total fall

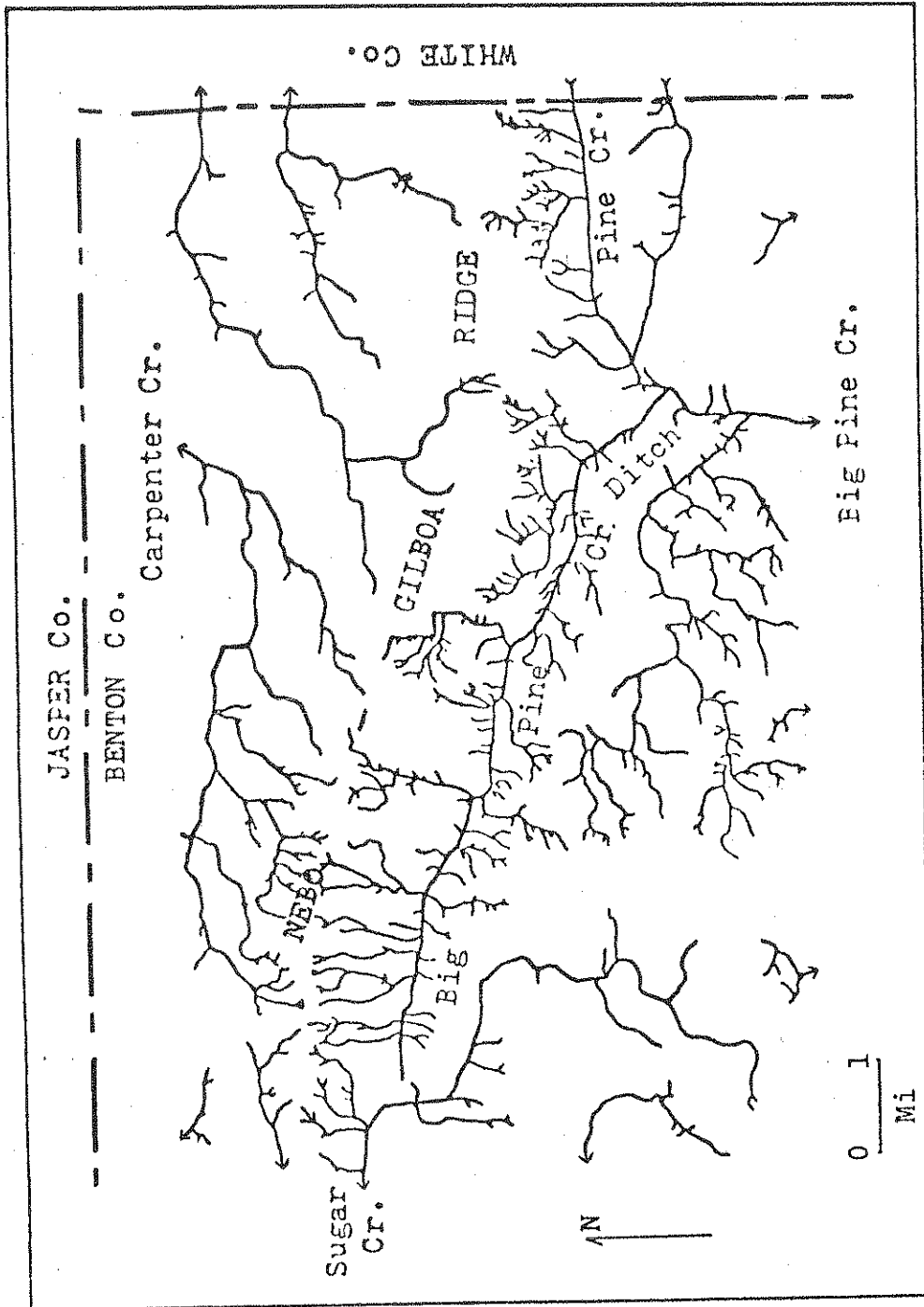


Figure 2 Drainage map of Gilboa, Pine, and Union Townships, Benton Co., Indiana

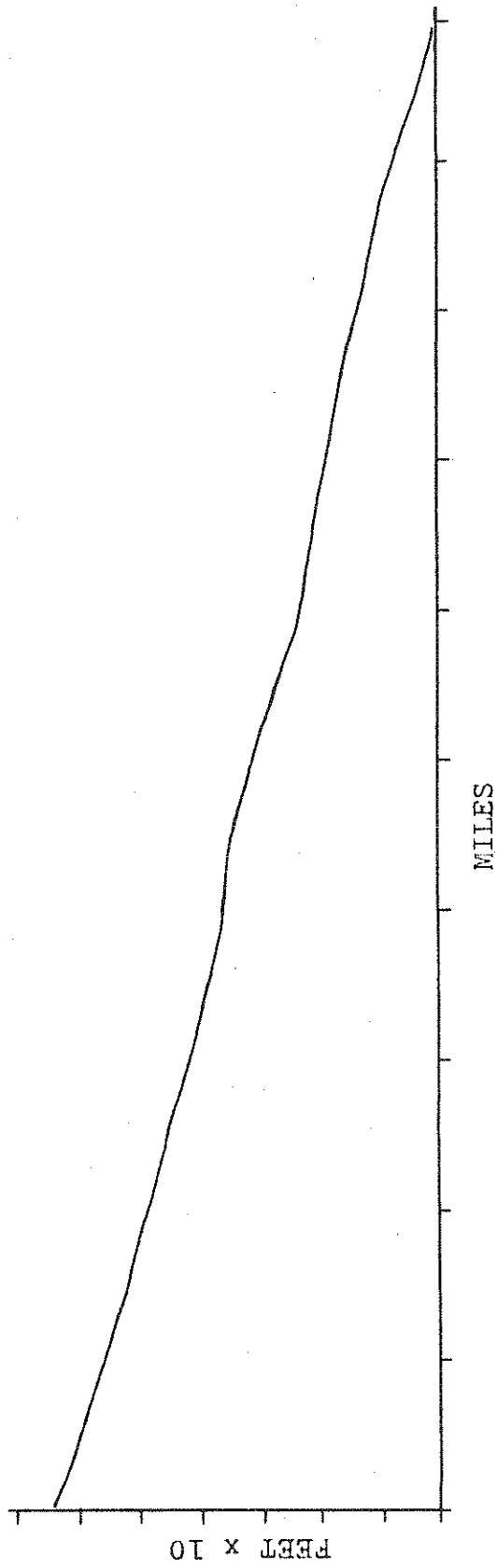


Figure 3 Channel profile of pre-channelized Big Pine Creek Ditch, from midpoint of Section 24 (T26N, R8W) to outlet.

of the creek was approximately 65 feet, giving an average slope of 6.3 ft/mi (.00117, in ft/ft or units/units; this convention will be used in reporting slopes throughout this report). No cross-sectional data are available, nor is their estimation possible, as the unfilled pre-existing channel has since been filled naturally by slope wash or disturbed by cultivation. Total main stream length was 10.1 miles from the railroad embankment (running north-south through the center of Section 24, the uppermost limit of the channelization project) to outlet.

An area of bedrock at or near the surface is indicated on the profile. Whether the stream flowed on this bedrock "high" or was above the level of bedrock prior to channelization is not known. However, as will be described subsequently, this bedrock plays an important role in post-channelization profile adjustment, and has formed a knickpoint situation in recent years.

At an early date, county authority determined that more extensive drainage and flood control projects were necessary for better production from the area's farmland. To alleviate flooding, stream systems were modified by construction of drainage ditches throughout many reaches. Since construction of many of these ditches, nearly constant maintenance has been necessary to retain efficient performance. Flow in many reaches has alternately scoured and filled stream beds, and in other reaches, considerable lateral erosion and meander development has occurred.

In April of 1930, Henry Budreau, a principal land owner in Benton County, proposed the construction of Big Pine Public Ditch and Drain to provide better drainage in Union, Gilboa, and Pine Townships. Local residents stated that the area would be "greatly and materially benefited by the construction of the ditch" and that "public health would be improved." Plans specified that two-thirds of the basin was affected by the improved drainage and about 37,850 linear feet of open ditch was to be constructed "to outlet and terminate into Pine Creek", which at this point had already been dredged. Projected estimations were for 159,240 yds³ of excavation (520 yds³ in limestone bedrock) at a total cost of \$25,600. Following are more specified plans and specifications (Benton County Court Records: Ditch Docket #137). The exact course the ditch was to follow has been plotted as shown in Plate 2. Stream gradients were set as shown in Table 1.

Cross-sections were designed to be trapezoidal, as shown in Figure 4, with side slopes of $1\frac{1}{2}:1$, and base widths as shown in Table 2. All trees and brush were to be cleared to allow 125 feet of right-of-way. Spoil piles were to be evenly distributed on both banks, leaving a five foot berm between the edge of ditch banks and the toe of spoil banks.

The channel profile of the channelized stream illustrated in Figure 5 was prepared from gradients reported in Table 1. It should be noted that bedrock was excavated and is present in the reach indicated in Figure 5. Total main stream length

Table 1. Slopes of Channelization Project

<u>Station</u>	<u>Slope</u>	Note: Station numbers are determined by measurements from the outlet in feet, i.e. station 15 is 1500 feet upstream from the outlet.
3 - 15	0.0027	
15 - 25	0.0010	
25 - 50	0.0014	
50 - 100	0.0010	
100 - 125	0.0012	
125 - 150	0.0020	
150 - 200	0.0015	
200 - 225	0.0012	
225 - 250	0.0010	
250 - 300	0.0008	
300 - 350	0.0010	

Table 2. Base Widths of Constructed Channel

<u>Station</u>	<u>Base Width</u>
3 - 15	12 ft
15 - 114	10 ft
114 - 206	8 ft
206 - 294	6 ft
294 - 378	4 ft

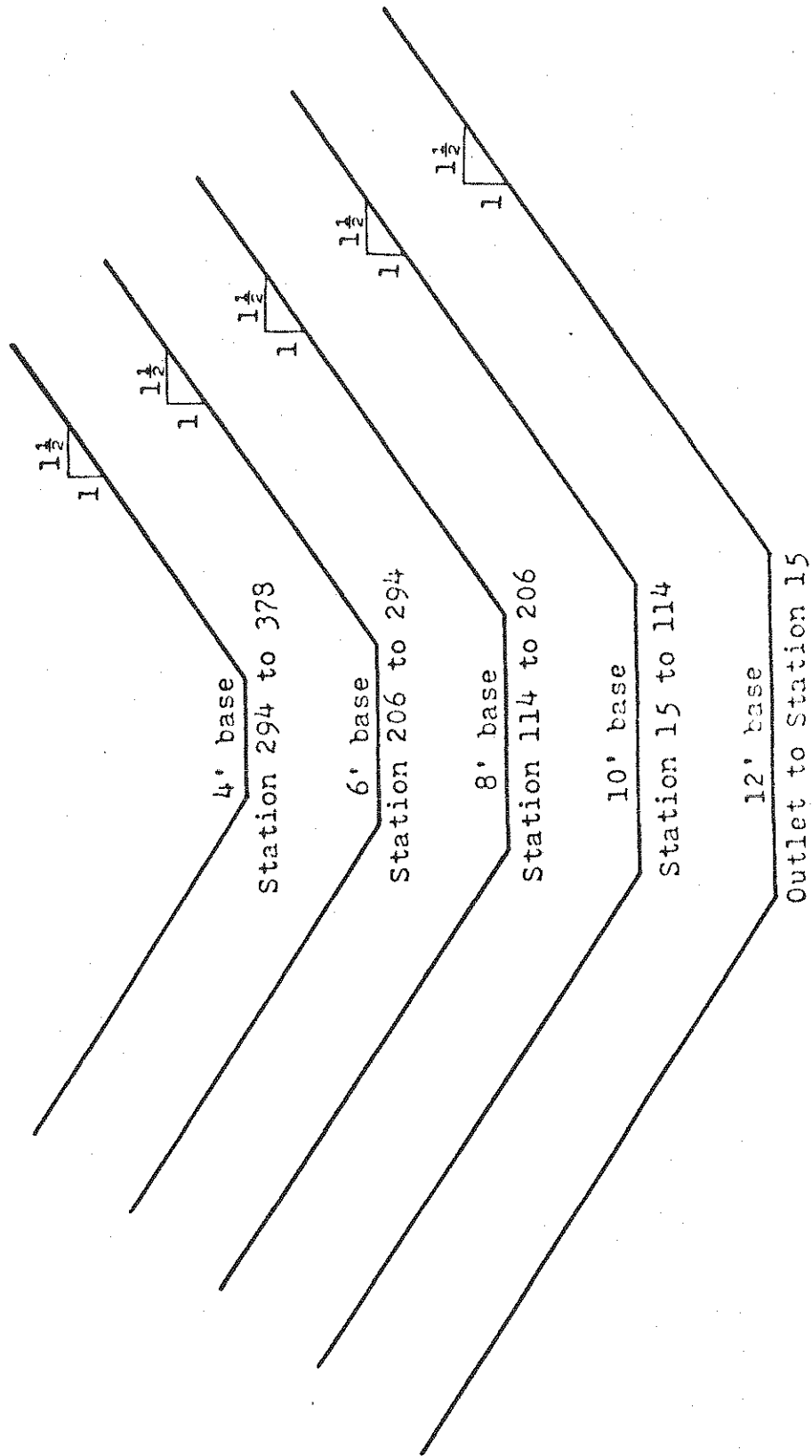


Figure 4 Planned cross-sections of Big Pine Creek Ditch as stated in channelization specifications. (Benton Co. Ditch Docket #137)

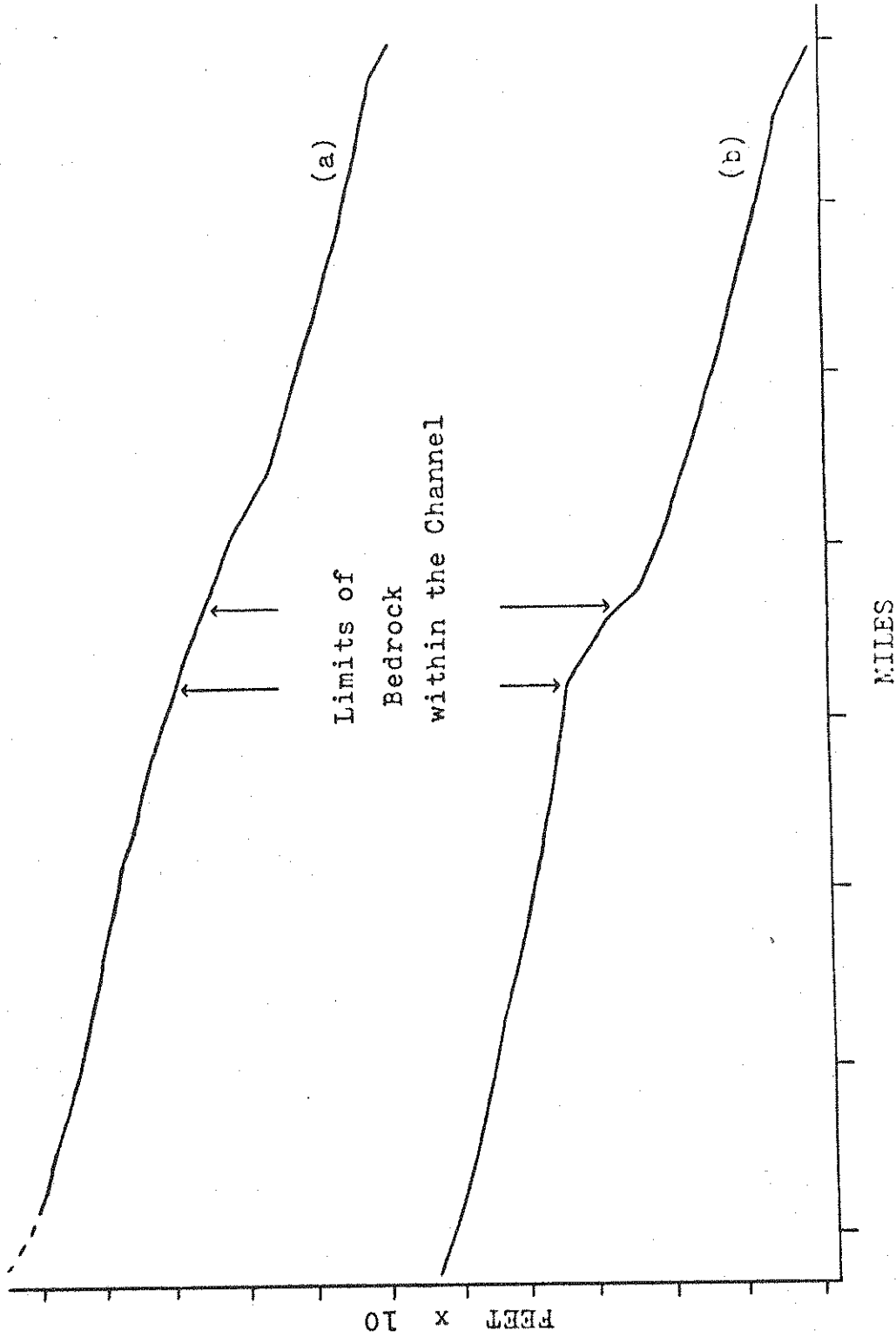


Figure 5 Channel profile of Big Pine Creek Ditch a) after channelization in 1932
(Benton Co. Ditch Docket #137) b) after 30 years of recovery in 1962.

was reduced from 10.1 to 7.2 miles, or by 30 percent, so average gradients were increased from 6.3 (0.00117) to 8.5 (0.00152) ft/mi. Fall of the main stream was reduced by seven feet by entrenchment of the headwater reaches.

Construction was completed by June, 1932, the major part of the work having been done by F.M. Horton and Co. of Chicago. Expenditures totaled \$14,492.50, considerably less than expected; 279 yds³ of rock were removed from the reach between stations 170 and 191.75.

For the purpose of completing the remainder of this current research on Big Pine Creek Ditch, it is assumed that the project was completed in accord with the plans and specifications. This assumption is based on the fact that the completed project was inspected and approved by the county surveyor and the engineer in charge. However, field investigations revealed that spoils were not everywhere used to fill the pre-existing channel, nor were they evenly distributed, so other deviations from the original plan are very probable.

Design Calculations

As no discharge measurements or flood frequency calculations were included in the ditch construction plans and specifications, design capacity of the project can easily be questioned. Presently, the only discharge measurements available for Big Pine Creek are taken at a considerable distance downstream, so are of no value in this study. Several methods of discharge calculations were tried, ranging from sim-

ple empirical formulae to more complex regression-type equations, in an attempt to estimate discharge at various points along the stream course. As expected, each method yields different estimates, with considerable magnitude of variation.

The method developed by Davis (1974) appears the most reliable for this study, as it was developed for streams in Indiana, and also seems to include the most important parameters for a basin of this magnitude. The equation for small watersheds is:

$$Q_t = b A^x R^y D^z Rc^u$$

where: Q_t is the discharge for a recurrence interval of t years in cfs (ft^3/sec)

A is the drainage area in mi^2

R is the watershed relief in ft

D is the drainage density in mi/mi^2

Rc is a soil runoff coefficient

and b, x, y, z , and u are regression coefficients.

Although the regression equation was developed using watersheds larger than $15 mi^2$, estimates within the basin down to $3.2 mi^2$ in drainage area seem quite reasonable. Estimates were compared with published discharge data for comparable basins in Indiana.

On this basis, discharges were estimated at six points on the main stream, where cross-sectional area was increased according to plans. Floods were calculated for 25-yr and 50-yr frequency events. Velocities were also estimated using

Manning's Equation:

$$V = 1.49 \frac{R^{.66} S^{.5}}{n}$$

where: V = velocity in ft/sec

R = the hydraulic mean radius in ft

S = the slope or energy gradient

n = Manning's roughness coefficient;

slopes as cited in construction specifications, and an n value of 0.03, a normal value for clean, straight streams, with no deep pools (Gregory and Walling, 1973). With the use of the velocity-area technique it was possible to determine whether the channel, as designed, could accommodate such floods. Table 3 was prepared for such determination. If the estimates are valid, the channel as designed would accommodate a 25-yr flood over the entire length, but not a 50-yr flood. The * values, as indicated in the table, are in excess of estimated maximum capacity. Channel dimensions with the gradients used in the channelization project are insufficient to accommodate these discharges at the indicated points.

These calculations (Table 3) indicate that the design parameters used in channelization were quite appropriate for this drainage basin. However, since project completion, the channel has undergone considerable deterioration, both in plan and profile and no longer drains the basin effectively. Attempts to trace the historical development of this deterioration, the evolution of pools and riffles, meander

Table 3. Velocity and Discharge Estimates for Big Pine Creek Ditch

Channel Base Width	Channel Slope	Calculated Velocity	Maximum Capacity	Flood Discharges	
				25 yr	50 yr
4 ft	0.0008 to 0.001	3.9 to 4.5 ft/sec	740 to 855 cfs	480 to 690 cfs	575 to 800 cfs
6 ft	0.001 to 0.0015	4.0 to 5.0	840 to 1050	690 to 920	800 to 1060 *
8 ft	0.0015 to 0.002	5.2 to 6.7	1190 to 1540	920 to 1120	1060 to 1275
10 ft	0.001 to 0.0014	4.8 to 5.6	1200 to 1400	1120 to 1285	1275 to 1460 *
12 ft	0.0027	8.1	2190	1285 to 1390	1460 to 1610

development, and bank erosion on Big Pine Creek Ditch are detailed in succeeding sections.

Changes in Morphology and Morphometry

Plates 3, 4, and 5 trace the development of the meandering channel and intend to show the stream course in 1938, 1963, and 1971, respectively. Each plate was prepared from aerial photography flown for the USDA in the spring of the year, in 1938 at a scale of 1:21,120 and in 1963 and 1971 at a scale of 1:15,840.

As stated by Yearke (1971), most major adjustments should be expected to occur immediately following construction as the channel seeks to restore a natural balance. In the six years immediately subsequent to project completion, the channel did make some drastic changes. Attention is drawn to several of the most obvious areas of deterioration as shown on Plate 3 representing the channel in 1938. Section 1 shows considerable meander development just upstream from the outlet and also upstream of the bend, both areas that were constructed with high gradients (0.0014 and 0.0027). The straight intermediate reach had a much lower slope (0.0010). Through Sections 35 and 34, some adjustment is apparent, but not to the extent of producing serious bank erosion. This type of pattern, however, may lead to further degeneration if not repaired. The most drastic deterioration appears to have occurred in Section 28, where the channel resembles the pre-channelized pattern. It is speculated that

construction methods at this point had insufficiently filled the pre-existing channel and it was subsequently reoccupied in the reach during periods of high flow. This problem area does not appear on the 1963 photography, so the cause must have been rectified and the channel repaired before further deterioration took place.

Unfortunately, no data are available on profile adjustments, but it is expected that considerable scour and fill occurred during the six year period and could possibly cause some lateral migration. Note should be made as to the condition of the channel in the vicinity of the bedrock high, as considerable adjustment will be occurring in that reach in the 1938 - 1963 time period.

By 1963, considerable lateral as well as profile adjustment is quite apparent, as shown in Plate 3 and Figure 5. Every reach that had been deteriorating in 1938 continued degeneration (except in Section 28, as previously discussed). Meander development in the outlet reach has increased in frequency and amplitude and seems by this time to continue into the northwest trending reach of Section 1, whereas in 1938 that low slope sector was essentially straight. The stream in Section 35 now has considerable sinuosity, until heading due west, where it is straight to section 34; at this point meandering resumes (see Plate 4). It should be noted at this time, that several property lines may fall between straight and meandering reaches, and some land owners may have done better and more frequent maintenance on the channel.

There is rather obvious deterioration on the western end of Section 34, which can be explained by the bedrock high in that area. It can also be noted on the channel profile of the stream in 1962 (Figure 5), that a definite steepening of the channel occurs immediately downstream as downcutting was effectively stopped on the bedrock but accelerated below this point. The increase in slope and corresponding stream velocity has apparently caused increased meander development. This development is presently continuing, as demonstrated by the change in channel pattern from 1963 to 1971.

Note should also be made of the meandering in headwater reaches in Sections 19, 24, and 30. These sections also seem to be affected by accelerated rates of deterioration (1963 - 1971), but apparently because of lower discharges and velocity, bank erosion and deterioration has not been as great as farther downstream (see Figure 14).

Present Day Big Pine Creek Ditch

In the Fall of 1975, the reach of channel in Section 34 that is experiencing excessive bank erosion was surveyed in considerable detail (Figure 6). Mapping interval was two feet, which shows quite clearly the bank cutting taking place on the outside of the meanders, and point bar deposition on the inside of bends (see Figures 7 and 8). Sinuosity of the reach has developed to approximately 1.2 in only 40 years. Figure 9 is a profile of the channel bottom through this reach, indicating the advanced stages of pool-riffle

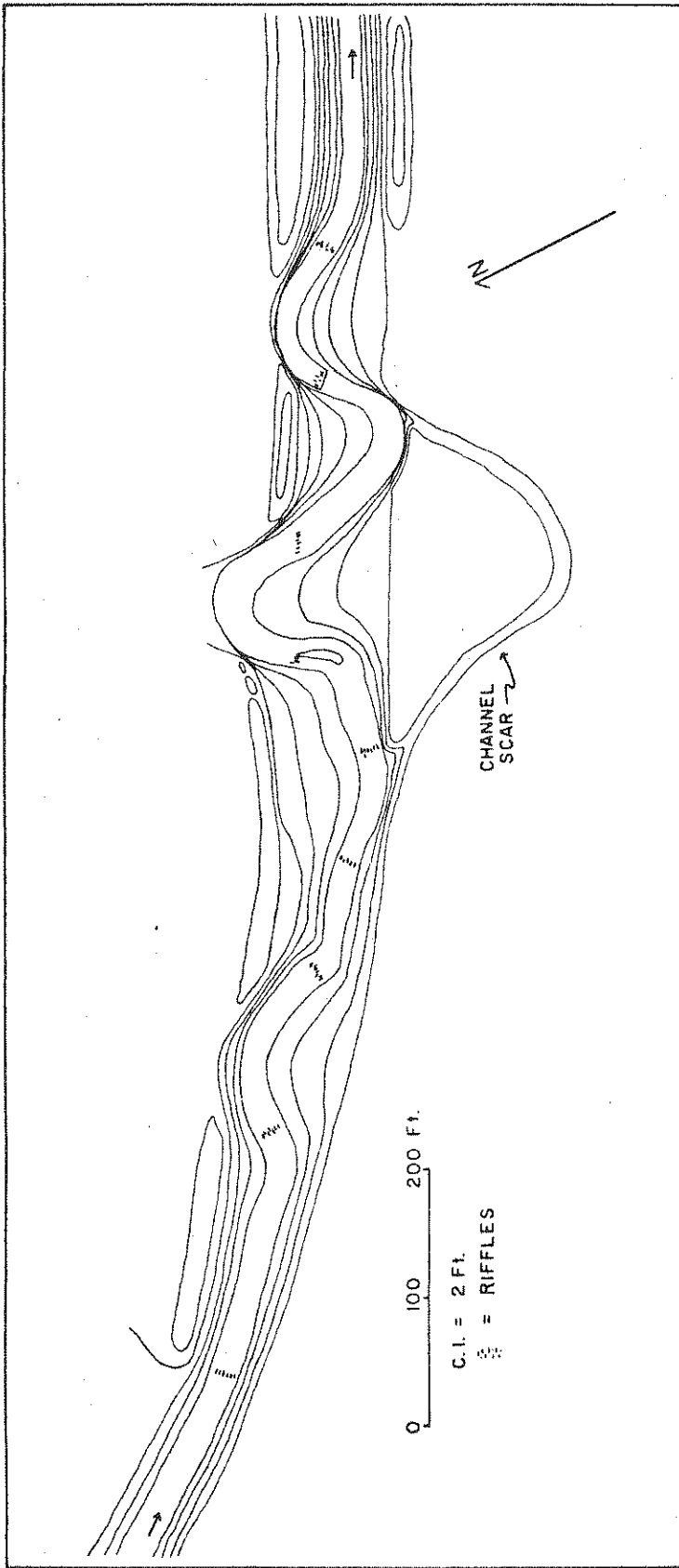


Figure 6 Map of survey reach (1975) in Section 34 showing channel deterioration.

End points are: west end is west line of Section 34 (T26N, R7W); east end is east line of NW $\frac{1}{4}$, NW $\frac{1}{4}$, Section 34.



Figure 7 Downstream view in the survey reach showing bank erosion and vegetated point bar.

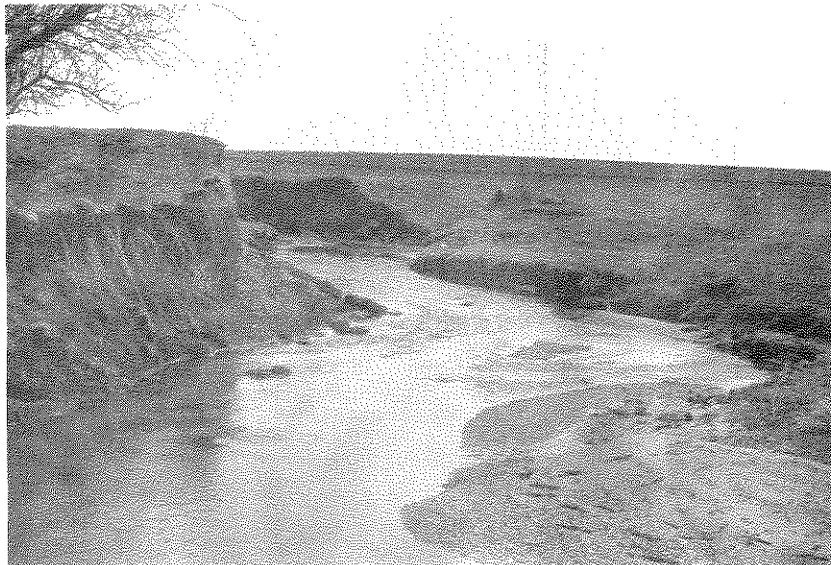


Figure 8 Downstream view in the survey reach showing bank erosion, point bar deposition, and riffle formation.

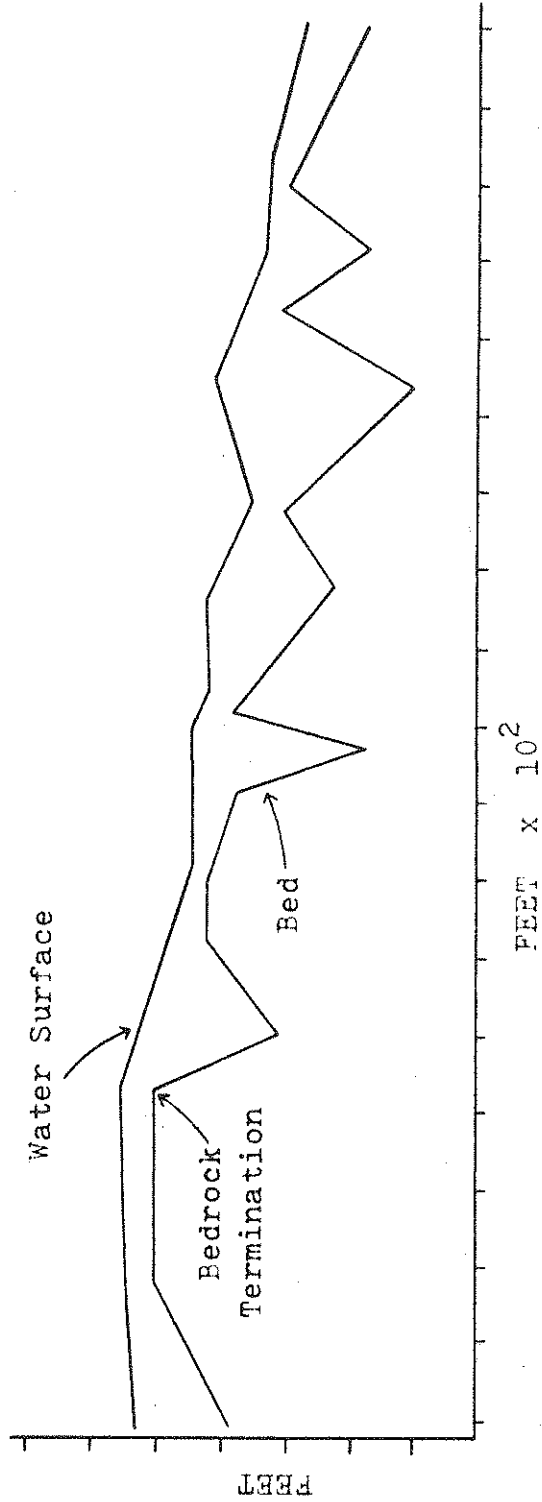


Figure 9 Channel profile of the survey reach indicating advanced stages of pool-riffle development (80X vertical exaggeration).

development accompanying meander adjustments. Note also the knickpoint conditions existing at the bedrock termination.

Profile Adjustment - Knickpoint Development

The term knickpoint is loosely defined as an abrupt change in gradient of the stream channel. Such a change in gradient was designed into the system in 1932, as shown at point A in Figure 10. Comparison of 1932 and 1962 profiles shows a headward migration and vertical exaggeration of the knickpoint, and downcutting below the knickpoint and in outlet reaches. The position of the knickpoint is presently stabilized by the bedrock high at that point, and some profile adjustment upstream from the knickpoint is also apparent.

Holland and Pickup (1976) describe similar profile adjustment in knickpoints developed in stratified sediments in a laboratory flume. Their experiment produced four basic results: 1) an aggraded reach upstream from the knickpoint, terminating on the downstream end at the fill-incision transition zone; 2) an oversteepened reach just above the knickpoint face; 3) the knickpoint face; 4) an incising reach downstream.

Close inspection of the Big Pine knickpoint shows very similar elements upstream and downstream from the bedrock high. Downstream incision is evident and seems to continue on to the outlet of the stream; this may have resulted from a lowering of local base level, by main stream modification in that area (see Figures 11 and 12).

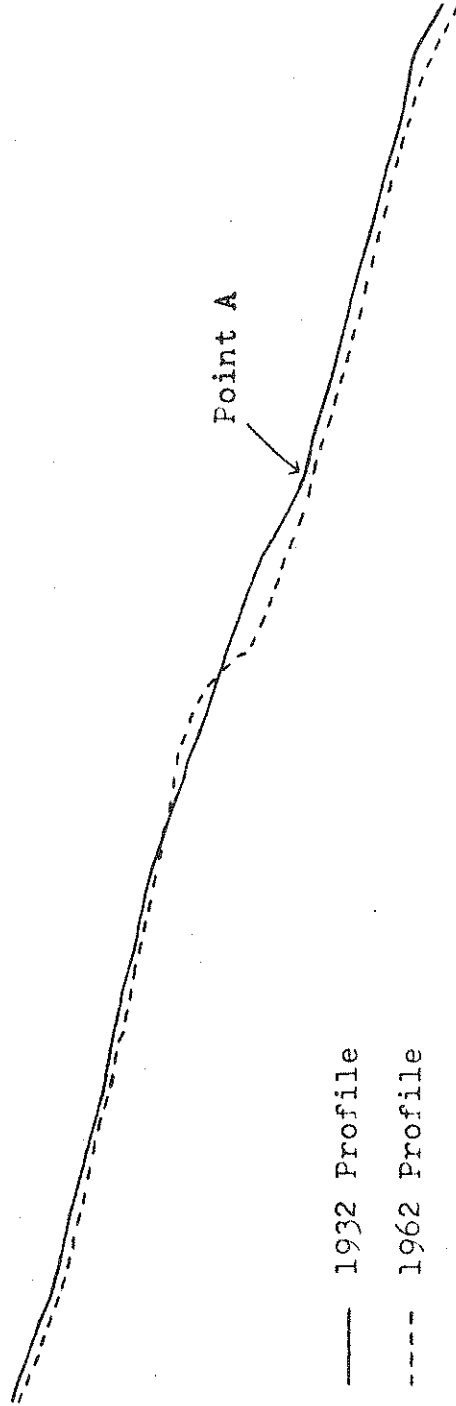


Figure 10 Comparison of 1932 and 1962 profiles of Big Pine Creek Ditch. Scales and endpoints are the same as in Figure 5.

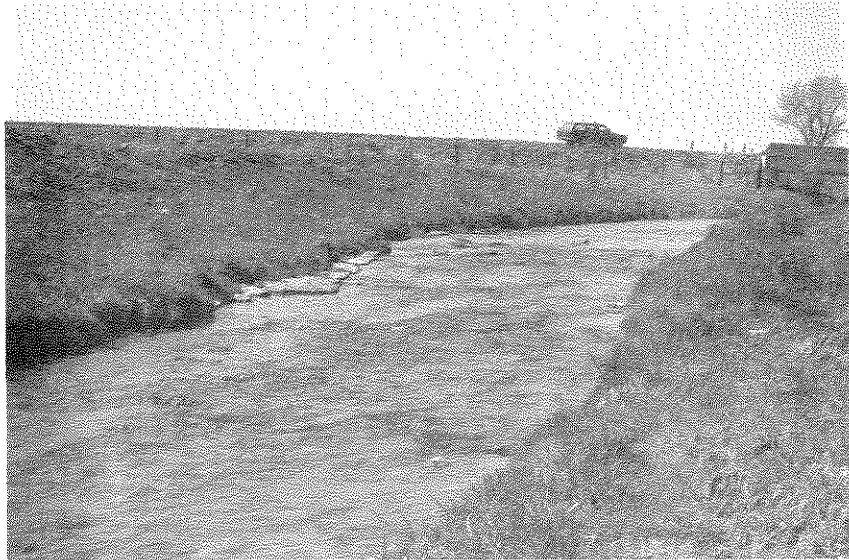


Figure 11 Upstream view just above knickpoint, showing bedrock in channel and steepened reach.



Figure 12 Upstream view of the knickpoint formed at bedrock termination.

Other experiments with flume-developed knickpoints, such as Brush and Wolman (1960) did not show aggradation and profile steepening above the knickpoint face; however, these experiments were conducted in non-cohesive sands. Holland and Pickup's knickpoints were produced in stratified sands, alternating with cohesive layers. This situation is indeed closer to that of the bedrock control present in Big Pine Creek Ditch.

Present Flooding

In conversation with local residents in 1975 and 1976, many complained of increased flooding in recent years, both in magnitude of land involved and frequency of flooding. Assuming that discharge has not increased appreciably in 40 years, investigation turned to deterioration of the channel as the cause of these conditions. Cross-sections were made at several points through the seven mile study reach, and these include areas of only slight deterioration, and those showing greater amounts. Figure 13a was constructed in Section 24, quite close to the headwaters and thus shows only minor changes since 1932 (see Figure 14). Figure 13b conversely shows considerable bank slumping, collapse, and deposition on the inside of meander bends.

These cross-sections were made in both straight and meandering reaches to show the differing types of degeneration: that is, slow slumping and creep of banks in the straight reaches, and lateral migration of channel and meanders,

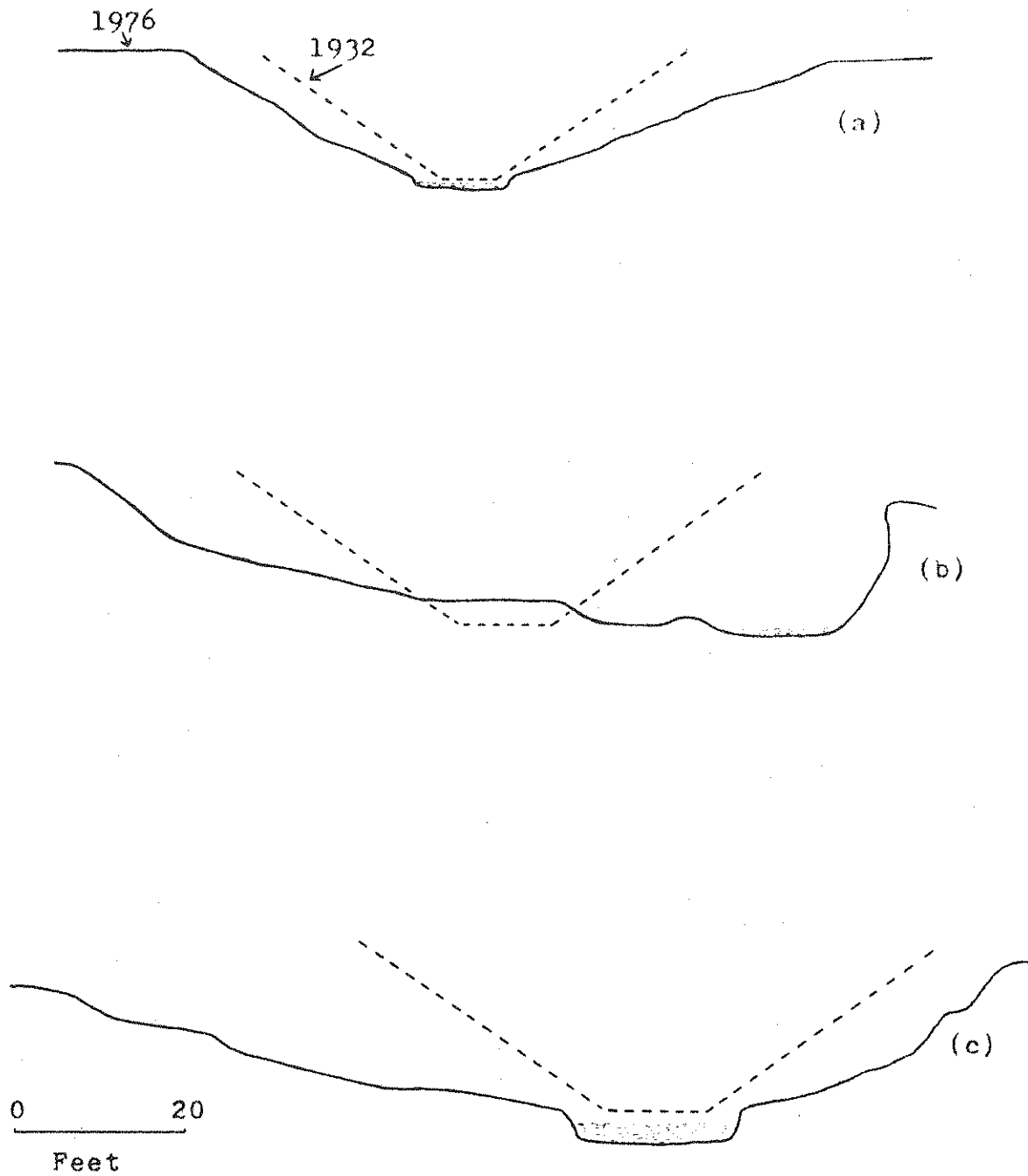


Figure 13 Cross-sections in: a) Section 24, T26N, R8W,
b) Section 34, T26N, R7W (downstream end)
c) Section 1, T25N, R7W, 0.5 mi upstream from
outlet. (these cross-sections are approximations)



Figure 14 Upstream view in Section 24, T26N, R8W, near headwaters of Big Pine Creek Ditch, showing minor bank deterioration and a meandering low-water channel.

causing undercutting and bank collapse, and point bar deposition on the inside of meander bends. Figures 15 and 16 were both constructed in straight reaches of the survey area in Section 34 (Figure 15 at the upstream end, Figure 16 at the downstream end). They show little lateral shifting of the channel, but considerable bank deterioration and retreat by means of slope creep and erosion. Near the east end of Section 34, the channel is experiencing lateral migration in the form of a series of rather tight meander bends. Figure 13b shows considerable migration of the channel on the meander bend itself. The principal erosional forces appear to be undercutting and bank slumping, with slump blocks often being evident in the channel. Figure 13c, again in a straight reach near the outlet in Section 1, shows the greatest amount of channel cross-sectional enlargement, and five to six feet of entrenchment.

Figure 16, the cross-section constructed in Section 34, at the downstream end of the survey reach previously discussed, was chosen for study of present day discharge accommodation calculations, as the owner is contemplating contracting additional modification of the channel through his land. As is quite evident in the cross-section (Figure 16), considerable bank deterioration and possible downcutting has caused a definite increase in channel cross-sectional area. Concurrently, however, stream gradients have greatly decreased and trees and brush have been allowed to grow on the channel banks.

1975



1932



0 10

Feet

Figure 15 Cross-section at upstream end of the survey reach. Channel flow at this point is on bedrock.

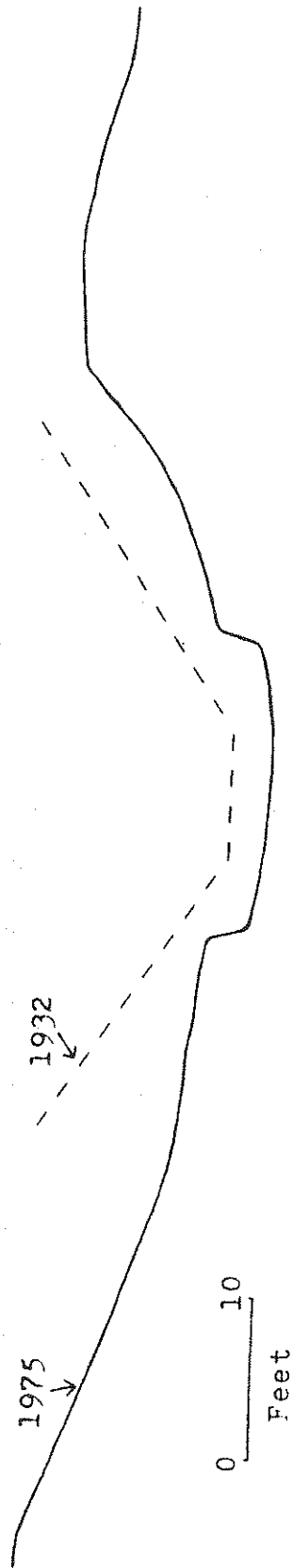


Figure 16 Cross-section at downstream end of the survey reach showing downcutting of the channel.

Again applying Manning's Equation to the new cross-sectional area and slope, and using a Manning n-value of 0.07, maximum velocity has been reduced from 5.2 ft/sec in 1932, to only 2.6 ft/sec in 1975. Increase in cross-section partly compensates for the velocity decrease, but the channel has still lost as much as 60 percent of its capacity in the reach. Comparing a present maximum capacity of 1100 cfs (425 ft^2 cross-sectional area X 2.6 ft/sec) to figures presented in Table 3 shows that this reach, which at one time could accommodate a flood magnitude well in excess of a 50-yr event, can now only accommodate a 25-yr flood. These calculations may be somewhat in error, as residents claim floods occur more frequently than have been estimated, but the estimates do demonstrate quite well the effects of channel deterioration and channel bank vegetation on stream capacity. (Since these calculations were made, the land owner cleared the trees and brush from the channel. No flooding has occurred since the clearing was accomplished, but it is anticipated that velocities will be increased sufficiently to decrease flooding problems.)

Pool-Riffle Investigations

Study of channelized stream reversion logically leads to investigation of the development, spacing, and configuration of pools and riffles. Obviously, the newly modified channel will have no pool-riffle sequences and may have very little of any type of bed form variation. Varying flow conditions and sediment load will soon allow scour and fill processes

to operate in different sections of the stream bed, and will form asymmetric shoals on alternate sides of the channel.

Keller (1972) proposed a five-stage model in the development of alluvial stream channels that traces the evolution of bed forms. The model begins with an initial stage of simple asymmetric shoals and ends with the most stable stage, which has pool-riffle sequences spaced at 5 to 7 times the channel width. Keller's model also incorporates meander development, and thus channel lengthening, by describing intermediate stages of development with incipient pools and riffles spaced at only 3 to 5 times channel width. With an increase in channel length, pool-riffle spacing increases (but not necessarily at the same rate), lengths of pools increase, and point bar deposits accumulate (see Table 4 and Figure 17).

Big Pine Creek Ditch seems to display several stages described in Keller's model. Detailed field investigation documents the idea that certain reaches of the stream show accelerated recovery rates, whereas others, especially those in the upper reaches (where there is less discharge, sediment load, stream power, etc.), show very little evidence of reversion to a more natural state.

Immediately after channelization, the entire stream would have been classed as in an "initial state". Keller's stage one, although including no pools and riffles, does incorporate asymmetric shoals which should not have been present in the present example. Therefore, addition of a sixth or

Table 4. Characteristics of the five stages in the development of alluvial stream channels. (after Keller, 1972)

Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
No pools or riffles	Incipient pools and riffles spaced at about 3 to 5 channel widths	Well-developed pools and riffles with mean spacing 5 to 7 channel widths and mode 3 to 7 channel widths	Well-developed pools and riffles with mean spacing 5 to 7 channel widths and mode 5 to 7 channel widths	Mixture of well-developed pools and riffles with incipient pools and riffles--mean spacing is generally 5 to 7 channel widths with a mode of 3 to 7 channel widths
The dominant bed forms are asymmetrical shoals	Dominant bed forms are asymmetrical shoals Pools and riffles are small	Dominant bed forms are pools, riffles, and asymmetrical shoals (mostly point bars) Pools are about 1.5 times as long as riffles	Dominant bed forms are pools, riffles, and asymmetrical shoals (mostly point bars) Pools are generally greater than 1.5 times as long as riffles	Dominant bed forms are pools, riffles, and asymmetrical shoals Pools are generally much longer than riffles

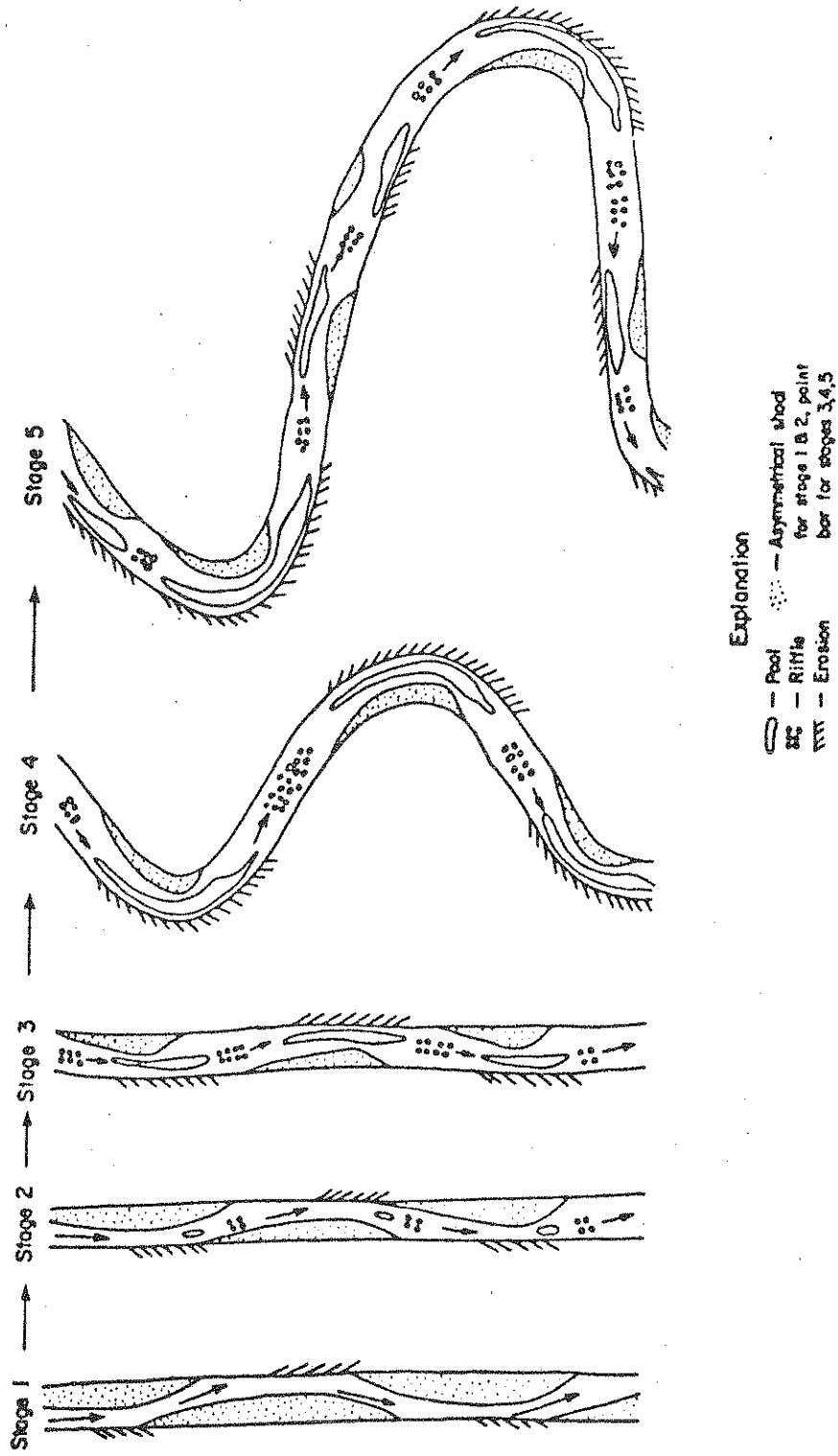


Figure 17 Illustration of the five stage development of alluvial stream channels.
(after Keller, 1972)

initial stage to the model is called for, in reference only to channelized streams (where artificial deepening, widening or straightening is employed). This initial stage may not exist for a long period of time; however, in small streams with small drainage areas, such conditions may persist sufficiently long to be considered in the model.

With passage into stage 1 of the proposed model, the Big Pine has behaved very much the same as under natural conditions, but at a somewhat reduced rate. High-level constructional banks and spoils have retarded meander development, which is essential in reaching a fluvial quasi-equilibrium state. Stages 4 and 5 may never be reached as meandering in these stages will certainly have reduced or negated the effectiveness of the original channelization project.

Field mapping and photography have been used to show reaches that demonstrate stages within the proposed model. Headwater reaches in Section 24 apparently lack any pool-riffle development, or even evidence of incipient asymmetric shoals (see Figure 14). Flows in these reaches are very low, with a drainage area of only 4 mi².

The western half of Section 35 quite recently has been restraightened to near original (1932) dimensions by the land owner. Plate 4, prepared from 1971 aerial photography, shows evidence of meander development and lateral erosion. Figure 18 indicates that this situation was indeed corrected, yet the channel has already reestablished stage one of the model. There appear to be no pools or riffles as yet, but the low

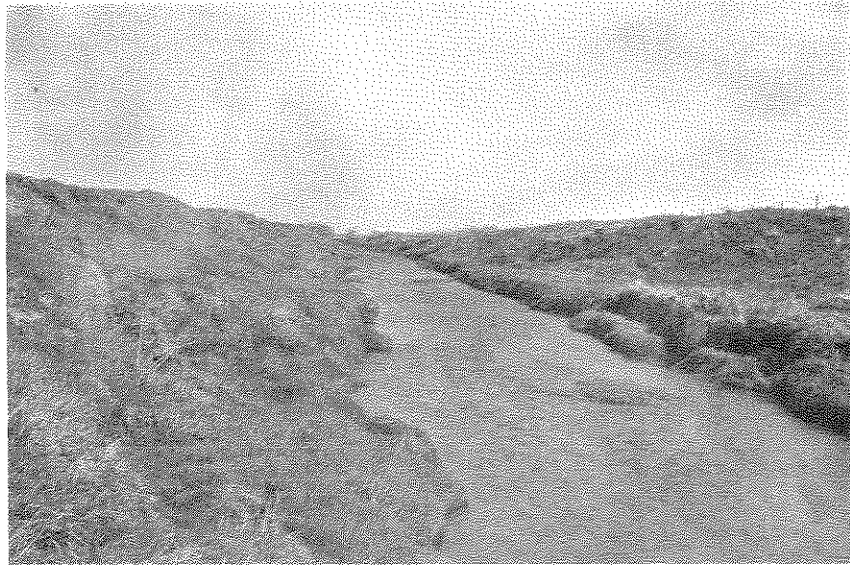


Figure 18 Downstream view of the reach in Section 35, T26N, R7W, recently restraightened and already showing asymmetric shoal development.

water channel shows asymmetric shoals and an alternating thalweg.

Several straight reaches, such as in Section 1, demonstrate a situation similar of stage 2 in the model, in having small, closely spaced riffles (~ 3 channel widths). Other straight reaches have well developed riffles and little evidence of meander development, and possibly fit into stage 3 of Keller's model (see Figure 19).

As indicated, some reaches of Big Pine Creek Ditch fit quite well into Keller's scheme, but it appears after considerable field investigation that others do not. The method of construction used in the project (the trapezoidal channel) has caused the low water channel in many reaches to meander within the confines of the constructed channel. Although in some areas these meanders have well developed pools and riffles, others seem to have none at all, merely a constant depth to a smooth, uniform, coarse-grained sand bed.

Possible explanation for such conditions in headwater reaches would include low discharge and velocity, thus providing little in the way of sediment transport and areal sorting. However, even in some reaches farther downstream these conditions exist, even where meander development would, by the model, put the stream in stage 3. In brief, it appears that the proposed model of Keller can be applied in some reaches, whereas in others, meander development appears to precede the evolution of stable, well developed pools and riffles.



Figure 19 Downstream view in Section 1, T25N, R7W, showing a well developed riffle and no meander development. Attention is brought to bank slumping and slope creep.

The most advanced pool-riffle development tends to coincide with reaches of greatest meander development in the seven miles of channel studied. Two reaches in Section 34 were selected as examples, one reach has already been discussed and shown in Figure 6; the second reach is at the opposite end of the section, and it apparently has "gone to pot" altogether. Both reaches seem to fit quite well into stage 4, in having pools in each bend and riffles at the inflection between meanders, and spacing of insufficient length to indicate stability.

It will be quite some time before stage 5 is reached in this area, because considerable meander migration is necessary before any stable channel forms can exist. Local residents are currently attempting to raise funds to have deteriorated reaches restraightened and cleaned out to provide increased flood capacity. The stream may never be allowed to regain any semblance of stable or even near stable conditions.

Reasons for Deterioration

With the discussion of areas of intense deterioration in mind, let us turn to consideration of the reason for degeneration of some reaches whereas other reaches undergo essentially no change. It is apparent that the least response to channelization would occur in headwater reaches where discharge, even under flood conditions, would have considerably lower magnitudes than in downstream reaches. However, examination of recent maps indicates that even in downstream

sections, reaches exist where little, if any, meander development is occurring. What, then, is the controlling factor that determines the rate of recovery of a channelized stream reach?

Existing bends incorporated in the original design of the channelization project would, in theory, cause bank erosion on the convex bank and thus initiate meander development. Although some of these original bends are within areas of meandering, some are not, and nowhere does it appear that meandering reaches begin at one of these bends.

Consideration should also be given to changes in material type, as transition from a clay till to a sand lens (see Figure 20) or silt pocket could indeed cause a change in channel characteristics. The most recent soil survey in Benton County was published in 1916 and is quite inadequate basis for such studies. The soils map makes very little differentiation of soil types in the limited area of flood plain, and only a few major types are identified within the entire basin.

Investigation again turned to examination of 1938 aerial photography, as these photos indicate less disturbance by cultivation of surface materials than does the more recent aerial photography. An attempt was made to more adequately delineate changes in surface material types, that could be used as a basis for explaining the different rates of deterioration. However, no such refinement was possible, as the photography of surface expression within the flood plain

area shows only minor color or topographic variation.

Soil variance within Benton County is quite limited. All the soils are developed on glacial till under prairie conditions. Most soils therefore are quite dark-colored, with mollic epipedons, except for those well-drained upland soils with considerable silt content. No true alluvial soils are developed within local flood plains, as the stream systems are too small.

Soil types associated in the area are silt loams such as the Parr, Fowler, and Corwin Series, and silty clay loams such as the Brookston and Clyde Series (Bushnell, 1958). These soils are extremely productive, and result in property values of as much as \$2,500 to \$3,000/acre. Any further study of material type would entail considerable subsurface investigation; parent material type changes may exist within the Big Pine Creek Ditch flood plain, but they are not evident at the surface.

As previously mentioned, spoils were neither evenly distributed nor consistently used to fill the pre-existing channel. In some sectors, spoils still create somewhat of a barrier to drainage of adjacent fields, whereas elsewhere spoils appear nonexistent. An in-depth study of spoil bank effect on stream stability is presently not feasible, as the banks have been modified by erosion and cultivation practices and, in some reaches, have been entirely removed for use in road construction (see Figure 21).

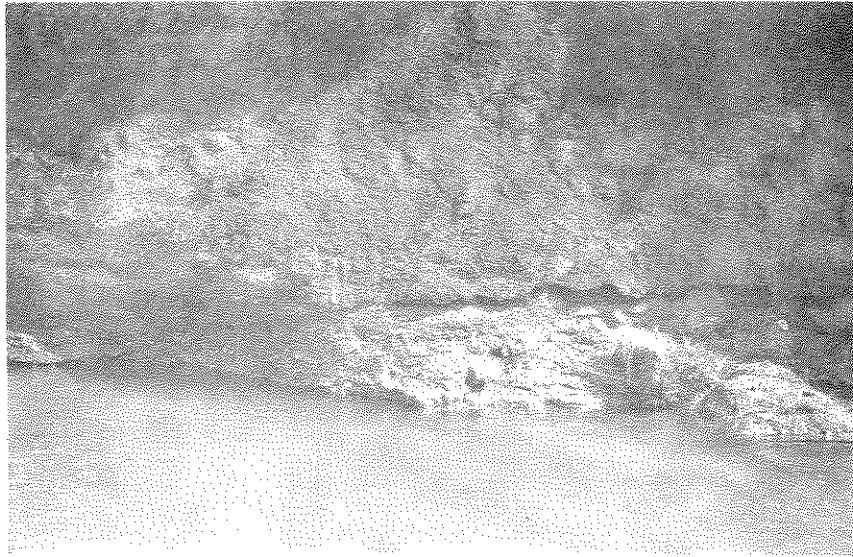


Figure 20 Typical subsurface sand lens exposed in cut banks along Big Pine Creek Ditch.



Figure 21 Upstream view in Section 1, T25N, R7W, demonstrating uneven distribution of spoils.

Conjecture is possible, however, about the spoils' effect on streambank stability. In some sectors spoils are responsible for impeding overland flow, and ponding behind banks is not uncommon. Water retarded by such ponding action seeks exit via subsurface routes. This underground seepage route can eventually cause instability and slumping by increasing pore pressures in the spoil and stream banks.

Methods of calculating this instability are quite involved, and could only be speculative, as any conclusive evidence of this type of instability has long since been destroyed. In other words, if bank instability is responsible for initiation of meander development, it can not be proven by reference to the present state.

Geomorphic Thresholds

The study of geomorphic thresholds is quite interesting in channelized streams, as such streams present a relatively unique condition. As in a laboratory stream (flume), channel slopes in modified streams are set on specific gradients, rather than allowed to evolve naturally. If such gradients are not held constant, but vary among different reaches, some reaches may develop pool-riffle sequences or show meander development whereas others may not.

This suggests that channel morphology may not respond gradually to alteration of conditions such as slope, but may tend to contain thresholds, or critical values, below which response will be negligible and above which the response

may be quite rapid. Schumm and Khan (1972) demonstrated such threshold values in the laboratory by varying slope and noting the sinuosity of the adjusted stream. Results indicated thresholds between straight (below 0.002 slope) and meandering channels (0.002 to 0.015 slope), and meandering and braided channels (above 0.015 slope). Similarly, Edgar (1973) attempted to show that variations in stream power ($\omega = \gamma QS$) were the cause of changes in sinuosity, that is, sinuosity varied with slope and discharge, and not slope alone.

Other parameters such as momentum, material type, and sediment load have been used to produce similar results. Additional research is necessary to determine what the main factors are that define sinuosity. Determination of threshold values could, however, be of great benefit in channelization and river-training projects. If the threshold value could be determined prior to construction, engineers could estimate how much straightening or slope modification the stream could tolerate without exceeding existing thresholds. Thus, planning could be carried out with confidence that destructive after-effects would not occur.

An attempt was made to define the relationship of such threshold parameters to phenomena observed on Big Pine Creek Ditch. Investigation of the relationship of slope and stream power to sinuosity was undertaken to see if any meaningful correlation existed. Sinuosities were measured for the entire study reach and were divided into different lengths, that is, into mile reaches; and into reaches with a constant five

feet of fall. Slopes were measured from the profile of the pre-channelized stream shown in Figure 3, and the 1932 and 1962 streams in Figure 5.

Fluvial geomorphology generally accepts that channel morphology and thus, sinuosity, are formed or determined by a bank-full discharge stage. As no cross-section or slope data are available for the prechannelized stream, estimates must again be used and, applying Davis' method (1974), the 2-yr flood is the closest approximation to bank-full stage. Estimates were made for numerous drainage areas or subareas within the 16 mi² basin.

Figures 22 and 23 are plots of slope to sinuosity and stream power to sinuosity (stream power = slope X discharge X the specific weight of water) respectively. As Schumm and Khan's study was done entirely in the laboratory using low discharge magnitudes, no correlation between the flume and natural situations can exist on the plots. It is also apparent that slopes on the Big Pine do not vary enough to produce straight or braided reaches; however, continuation of the curve to lower slopes would indicate a threshold condition. Validity of this plot can be questioned, as separate or different curves could be drawn through the two trends shown on the plot.

Edgar's (1973) research, although concentrated mostly in the flume, was also applied to the natural situation for 37 stream reaches in Alberta (see Figure 24). The plot from Big Pine Creek Ditch approximates both the shape and

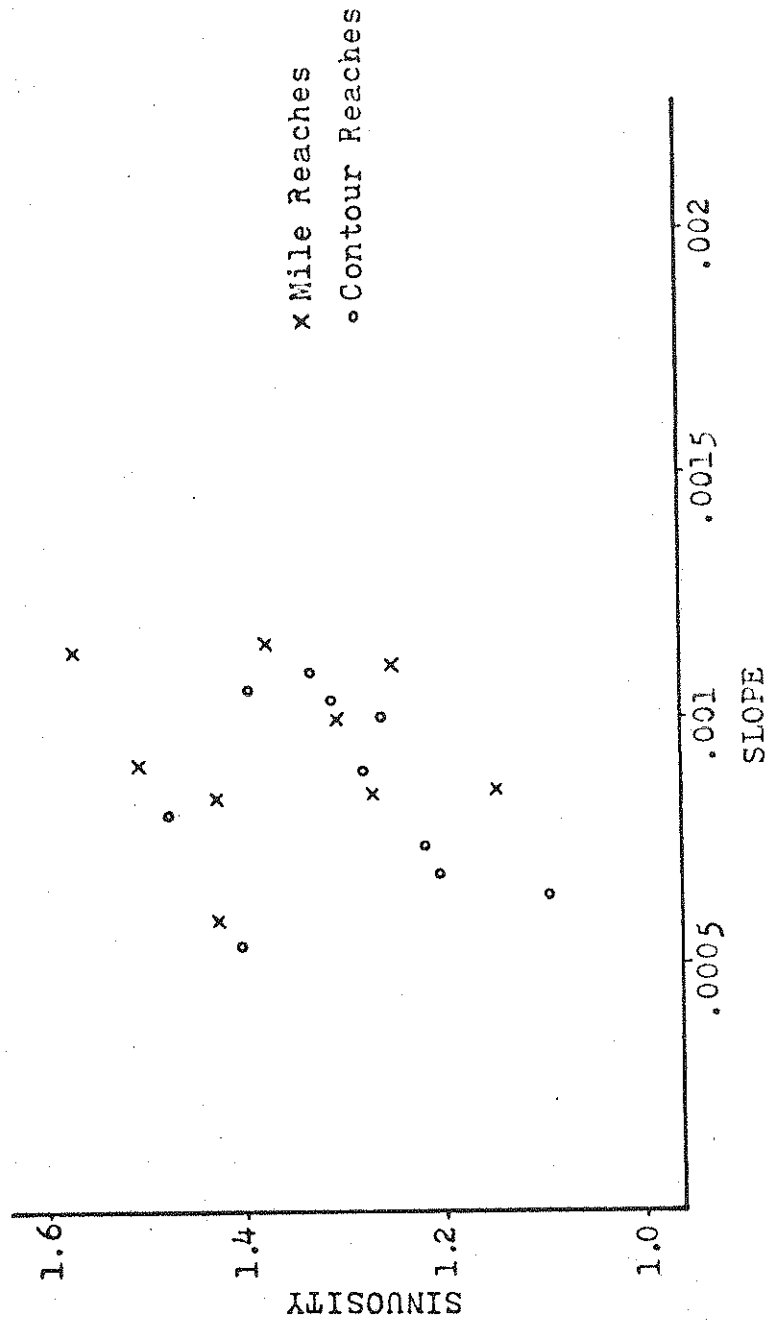


Figure 22 Variations of sinuosity with slope for pre-channelized conditions on
Big Pine Creek Ditch.

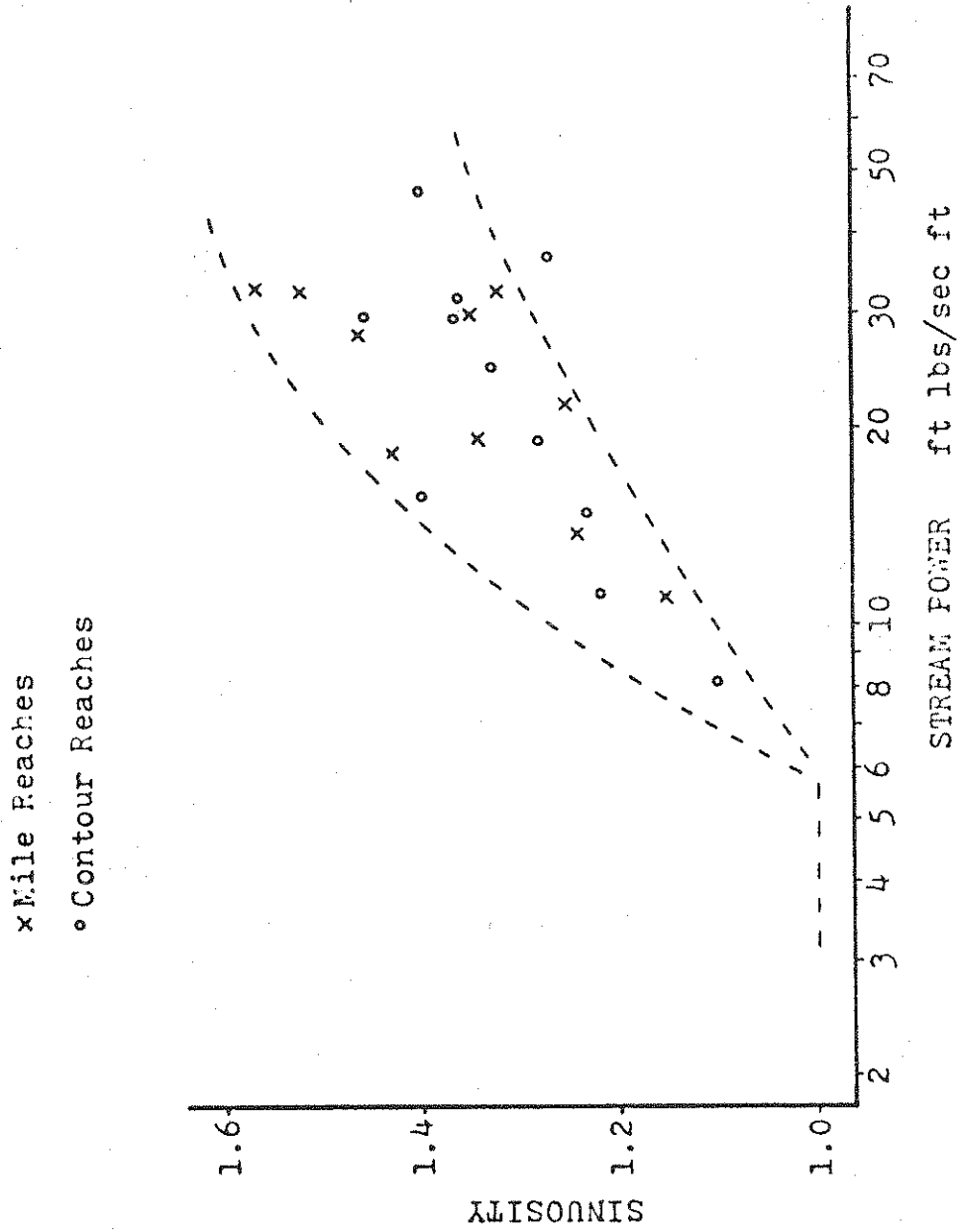


Figure 23 Variations in sinuosity with stream power for pre-channelized conditions on Big Pine Creek Ditch.

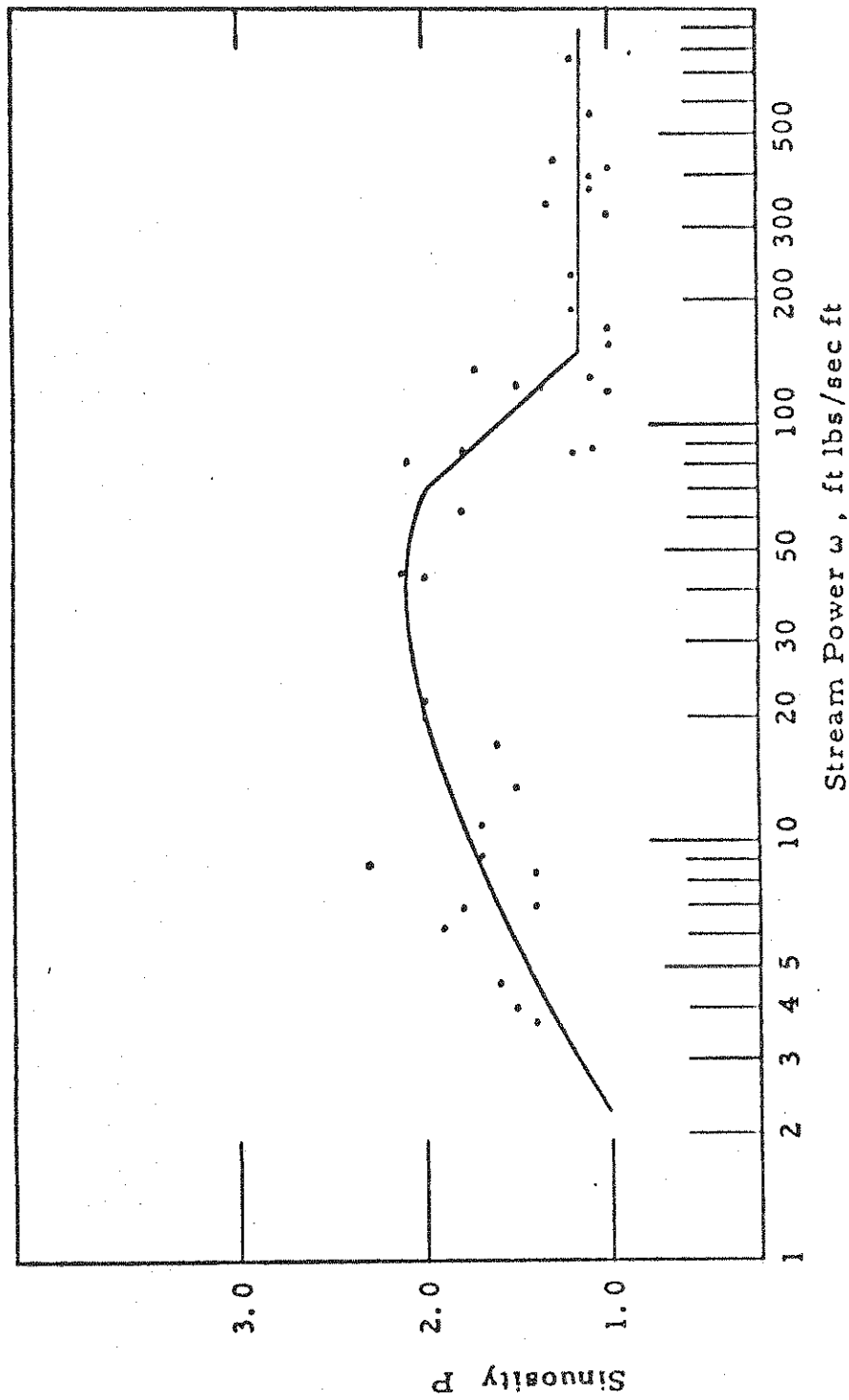


Figure 24 Variations of sinuosity with stream power for 37 stream reaches in Alberta.
(after Edgar, 1973) The data are from Kellerhals, Neil, and Bray, 1972.

magnitude of Edgar's curve. Again, stream power does not vary sufficiently to produce a sinuosity of one, but continuation of the curve does indicate existing threshold conditions. The curve or envelope formed by relating stream power to sinuosity appears more valid than that of slope to sinuosity.

If Big Pine Creek was in a near-equilibrium state prior to channelization, the envelope developed for that time period represents the stream in its most stable condition. The author believes that any deviation from this envelope represent instability and thus indicate that readjustment is forthcoming. Channelization produces just such deviations, to an extreme value by reducing sinuosity to one, and concurrently increasing slopes. In theory, any movement within the envelope will maintain the stability of the natural state. In channelization, if sinuosity is reduced, slope, and thus stream power, must also be reduced. This can only be accomplished by the use of drop or weir structures.

In the readjustment process it is anticipated that at any one point in time, slope or stream power curves could be constructed to represent the stream at that time. It is also believed that these curves will tend to migrate upwards from a sinuosity of one, to the stable curve that has already been determined. Curves were developed for the stream in 1938, 1963, and 1971, using slopes from 1932 and 1962 profiles. These curves appear in Figures 25 and 26, with different years represented by different symbols. Although the

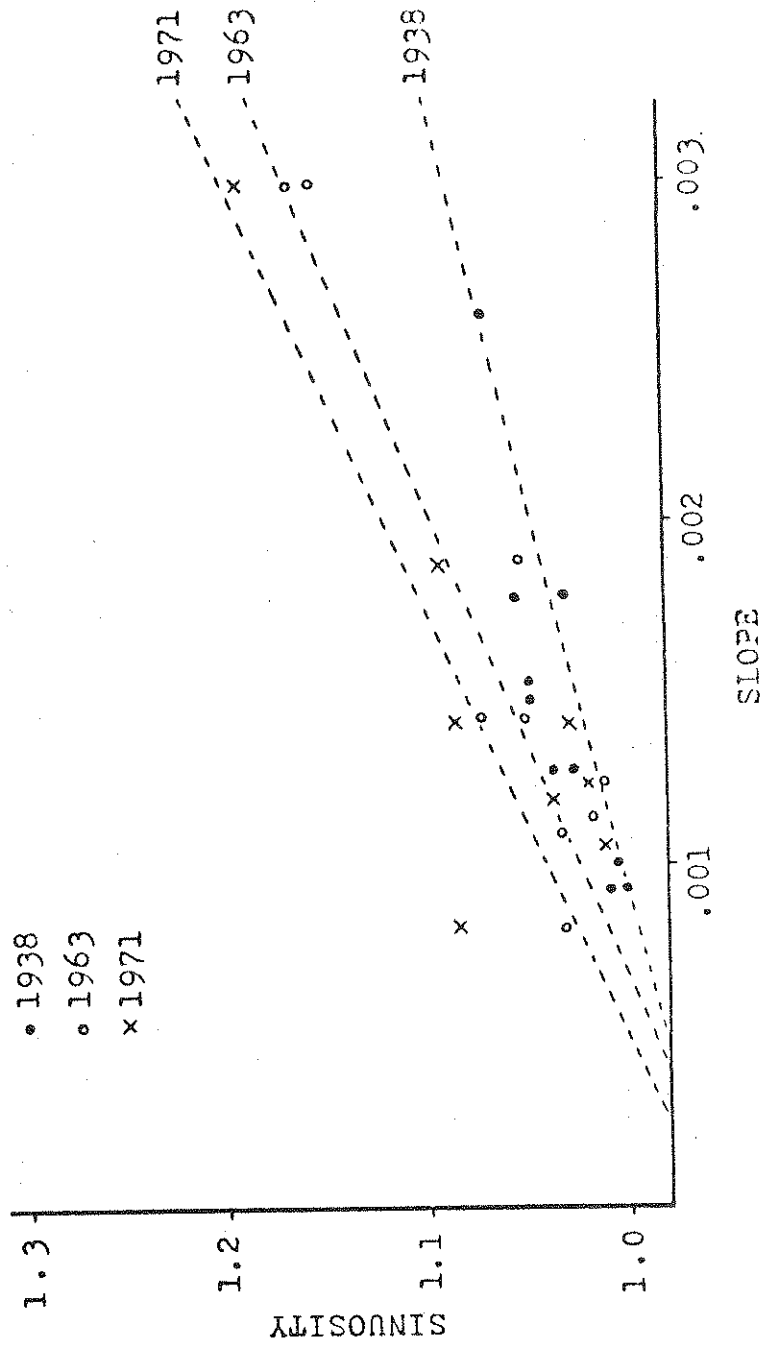


Figure 25 Variations of sinuosity with slope in Big Pine Creek Ditch in 1938, 1963, and 1971.

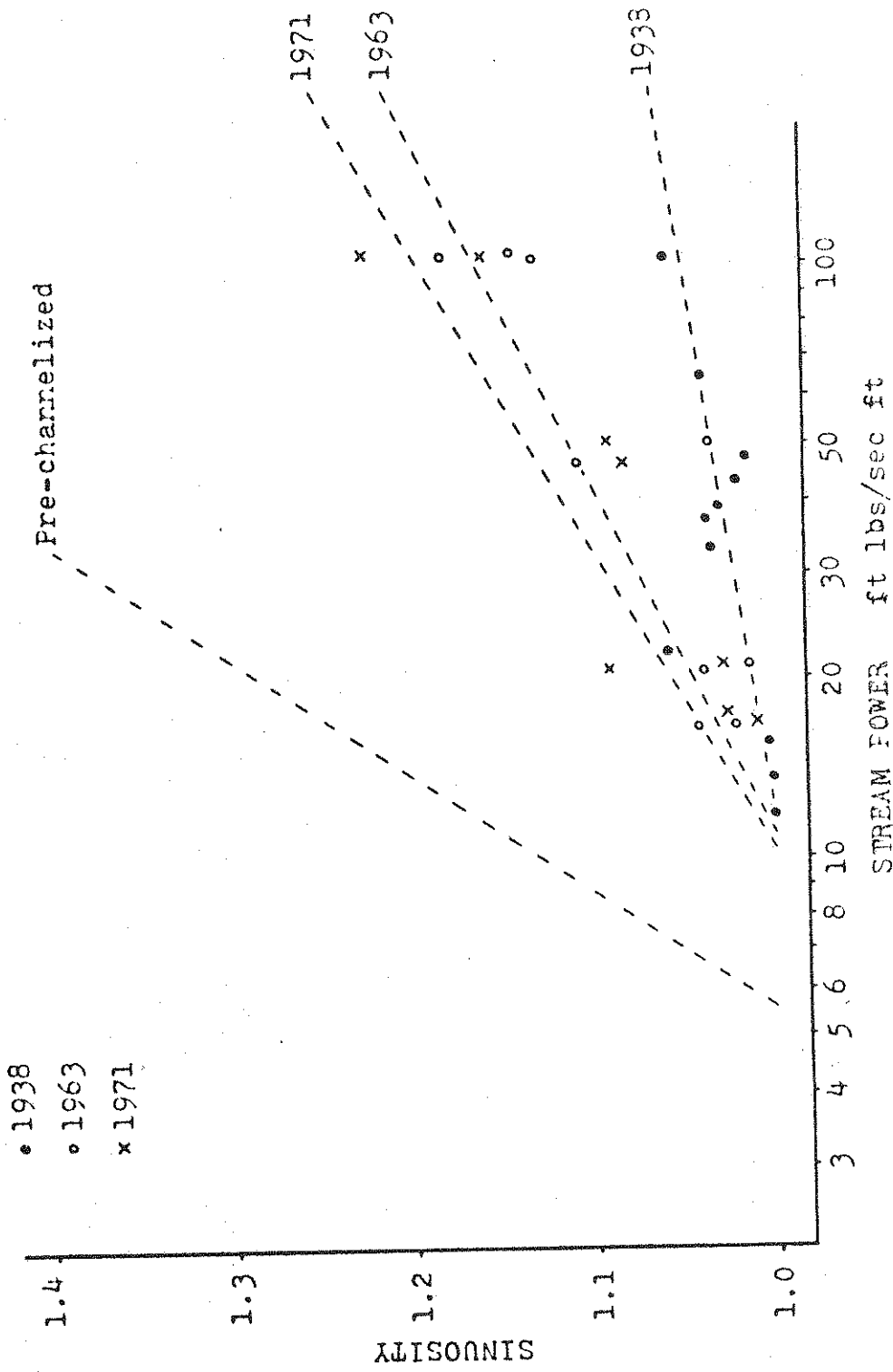


Figure 26 Variations of sinuosity with stream power on Big Pine Creek Ditch in 1938, 1963, and 1971.

process of curve fitting through these points is more difficult than on the pre-channelized stream, definite trends exist. Some very low points can be eliminated, as they are very possibly caused by the interim maintenance measures performed by the local residents. Such maintenance has most definitely affected the channel in several sections.

More information can be gained from these curves than has previously been suggested. A definite migratory trend is evident in curves representing 1938, 1963, and 1971, with movement in the direction of the pre-channelized state. A rate of recovery can be estimated from these curves; however, caution must be exercised as this rate may tend to fluctuate with time, and may also fluctuate among various reaches of the stream. In other words, recovery rates may be increasing in some reaches, but simultaneously decreasing in others, and general trends in recovery may experience fluctuations spread over the entire seven mile long reach. Although meander development in the survey reach in Section 34 currently appears to be experiencing accelerated recovery rates, as will be discussed subsequently, rates over the entire stream seem to be decelerating. Recovery rate fluctuations may also partly explain the point spread that is apparent on the stream power to sinuosity plots.

Lines were fitted by visual inspection to each set of points representing the various time periods, and slopes were calculated for each line. These slopes represent a curve of stream power related to sinuosity (when plotted on

semi-log paper, appear closer to straight lines) for the time period under consideration. These slopes were subsequently plotted against time, and appear as a curve in Figure 27. Extension of this curve to the slope of the pre-channelized stream power vs. sinuosity line would thus give some idea about the time required for the stream to regain equilibrium conditions. The graph shows that by the year 2080, or after 165 years of recovery, Big Pine Creek Ditch, if allowed to deteriorate under natural conditions, would again be in a quasi-equilibrium state.

A histogram is used to show the change in recovery rates, or amount of recovery per year. Extension of this trend indicates, as predicted, that recovery rates were high initially, and have been decreasing since. This does not, however, discount the fact that some reaches are presently experiencing accelerated erosion rates and thus a rapid increase in sinuosity. Similar curves for estimating recovery time were not developed for the slope to sinuosity relationship, as there was question as to the validity of the slope formed by points representing pre-channelized conditions.

Sources of Error

There are several steps within the research methodology that depend entirely on estimates. Although these estimates appear accurate in every respect, there is room for error. There follows a brief list of the areas prone to error:

- 1) Misinterpretation of aerial photographs during any stage of the research (that is, 1938, 1963, or 1971 photography).

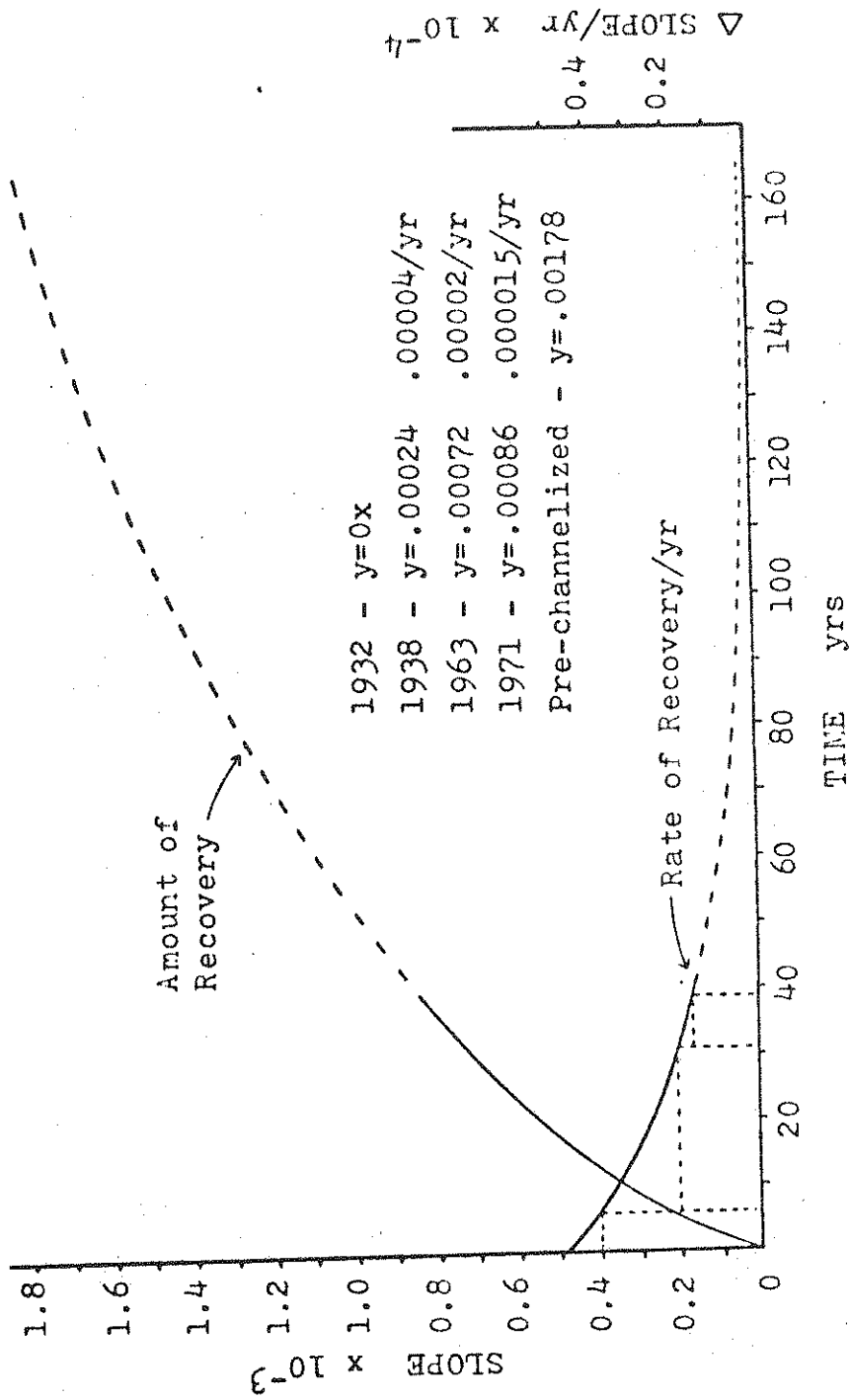


Figure 27 Estimation of amounts of recovery with time and rates of recovery with time, from channelization in 1932 until total recovery after 165 years.

- 2) Deviation between actual construction results and original plans and specifications of the project.
- 3) Error in discharge estimates, and use of 2-yr flood event as equivalent to bank-full stage.
- 4) Error in topographic map construction, as contours were used to draw profiles of the pre-channelized stream and the stream in 1962.
- 5) Error in velocity calculations, because the Manning n-value is normally extremely difficult to estimate.

Application of Threshold Concepts to Design

Although much of the foregoing discussion about thresholds and recovery rates is speculation, the author believes that the application of such concepts could lead to better design of stable channels. The envelope for the relationship between stream power and sinuosity seems to represent the stable condition or that developed in the quasi-equilibrium situation. Admittedly, there is a considerable point spread shown on the plot, but once again, this may represent a threshold between stable and unstable conditions. Points indicated as lying within the envelope would not result in readjustment.

Definition of a stability envelope for any stream to be modified would allow the engineer to design a more stable drainage project. If sinuosity is to be reduced, then slopes should also be changed to allow the new point (of the modified stream as plotted) to remain within the stability

envelope. As reducing sinuosity necessarily involves increasing the slope, the introduction of drop structures at various intervals would allow straightening with less change in gradient (see Figure 28).

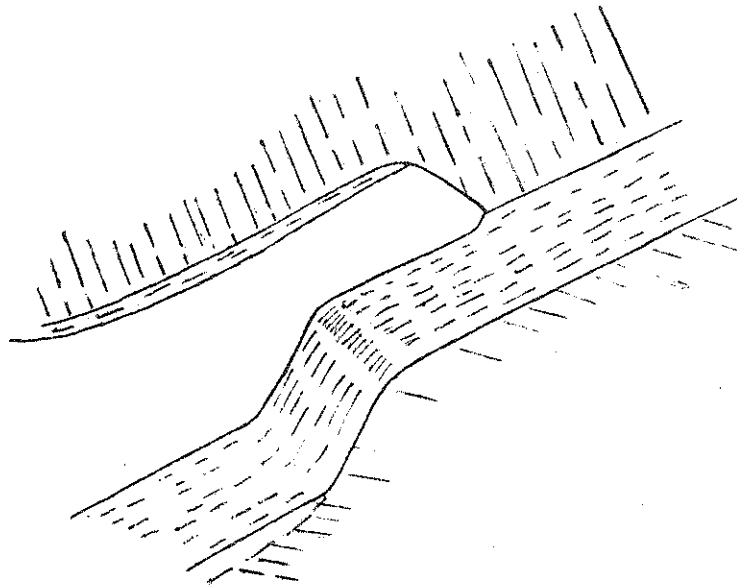


Figure 28 Illustration of possible design of concrete drop structures.

Obviously this type of structure is subject to peripheral scour and is not a good solution in large watersheds. However, small agricultural watersheds make up a large percentage of the channelized streams in the Midwest.

NEW ENGINEERING DESIGN

Until further research and development of concepts such as threshold values provides a definite solution to instability of channel morphology, other procedures and designs must be instituted to minimize the adversities of channelization. Yearke (1971) recommended these measures after intensive study of the Peabody River relocation:

- 1) Examine the upstream reach (~0.5 mi) to identify material within the channel and determine its susceptibility to erosion. Try to predict reaction of the stream after construction.
- 2) Attempt to duplicate the original hydrologic properties of the natural stream in relocated reaches. Approximate the slopes of the natural channel. " . . . for long channel relocations, this might be accomplished to some extent by the introduction of artificial meanders . . . " Drop structures could be utilized if the channel must be shortened appreciably; however, such structures are vulnerable to damage in extreme flooding.
- 3) Most serious adjustments should be expected to occur immediately following construction, as the channel quickly seeks to restore its natural balance.
- 4) Deposition downstream should be tolerated.
- 5) All feasible measures should be taken to avoid damage to fish and wildlife, prior, during, and after construction.

Several basic concepts of fluvial processes can very easily be applied to improvement projects and could produce

more efficient stream channels. These ideas have existed for many years, but have never been properly applied, possibly because of additional cost or possibly because of spatial limitations. Case studies and research show that the cheapest initial construction methods are not necessarily the best, nor ultimately the cheapest. It is safe to assume, therefore, that a greater initial investment will be justified by reduced long-term maintenance costs.

It is generally accepted that natural channels are maintained at bank-full discharge or flows near this stage. Leopold et al (1964) believe that bank-full stage is attained once every 18 months, whereas others believe this can range from nine months to two years, depending on the climatic variation. Channelization projects, however, must be designed to accommodate 25-yr to 50-yr flood discharges. Thus, the stream of bank-full or less discharge can not be expected to maintain a channel designed for a 50-yr flood. Yet, in many projects, the designed channel is trapezoidal in shape, with no specific design for a separate low-water channel for periods of less than flood flow. This practice may be the principal reason for low-water channel instability, increased mid-channel bar deposition, and biologic sterility. Keller (1975) suggests the construction of a pilot channel, maintained by 2-yr floods (or less), superimposed on a larger flood control channel, designed for the lower frequency flood. If total flood control is desired, such larger channels would be analogous to construction of an artificial or confined flood plain.

The low water channel would be allowed to meander and would have near natural pool-riffle sequences to permit a productive aquatic habitat. The flood channel could even be vegetated to reduce wildlife displacement. In urban or suburban areas, if land is available, such artificial flood plains could ideally be used for recreation (see Figure 29).

Obviously, the small-scale agricultural drainage system would not require anything as elaborate as a channel-in-channel configuration, but the problems remain even in small streams. The Soil Conservation Service (1971) has proposed several techniques to improve fish productivity and other aquatic life by providing variety in flow conditions. Construction of artificial pool-riffle sequences has been suggested; however, basic principals of fluvial processes again have been ignored. Riffles would be fabricated by the placement of rip-rap at designated intervals along the stream course (see Figure 30). Although the intent is sound, as designed, the widened pool areas would soon silt up as velocities would always be reduced in such pools.

Application of the concept of convergent and divergent flow could be used to prevent such siltation (Keller, 1976). As discussed by Leliavsky (1966) diverging flow causes velocities to slow and thus material is deposited, whereas converging flow increases velocity and causes bed scour. In natural stream conditions, flow converges in pools and diverges in riffles, an idea quite inconsistent with high velocity riffles, and low velocities in pools at low flow.

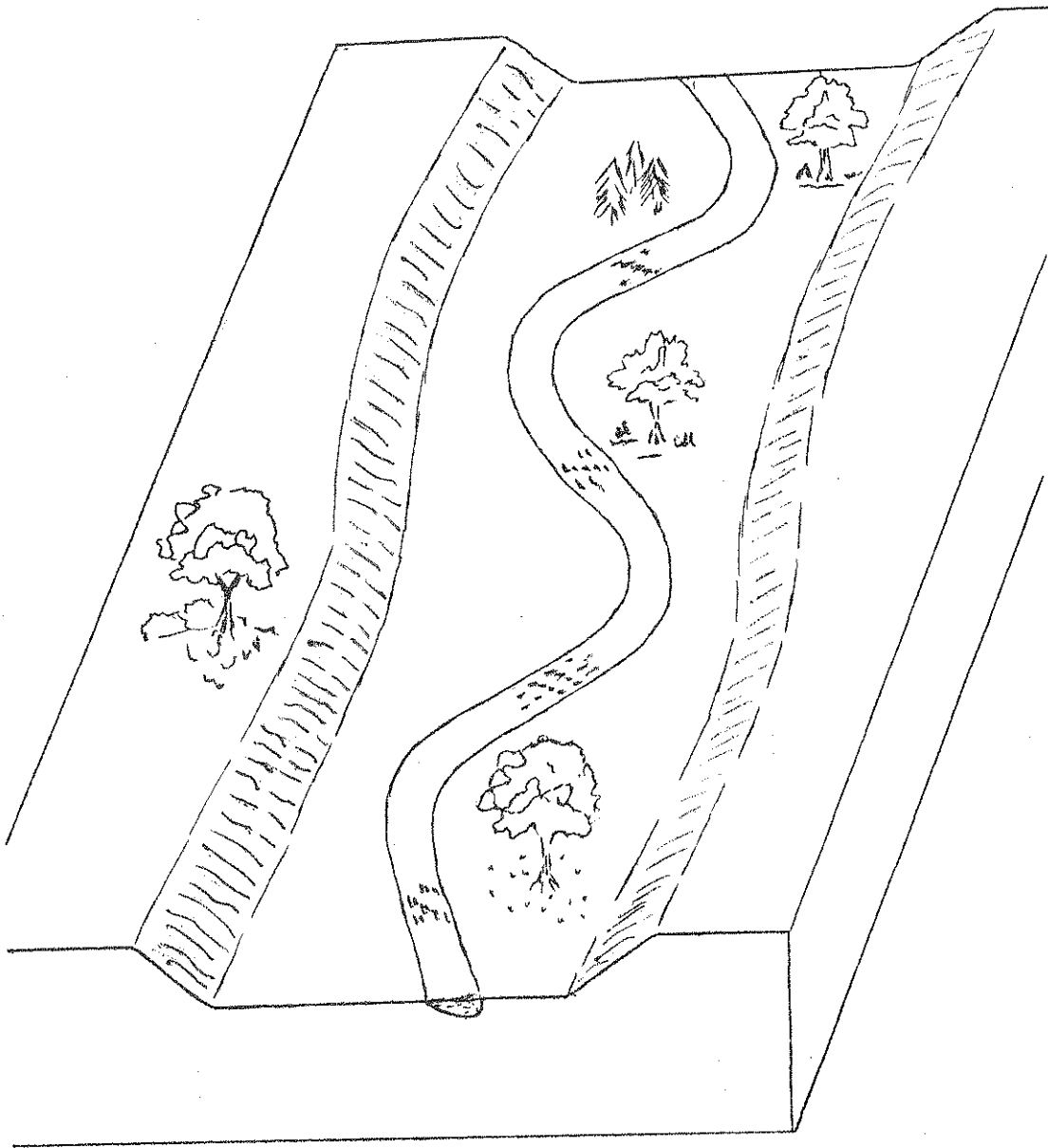


Figure 29 Illustration of an ideal channel-in-channel configuration.

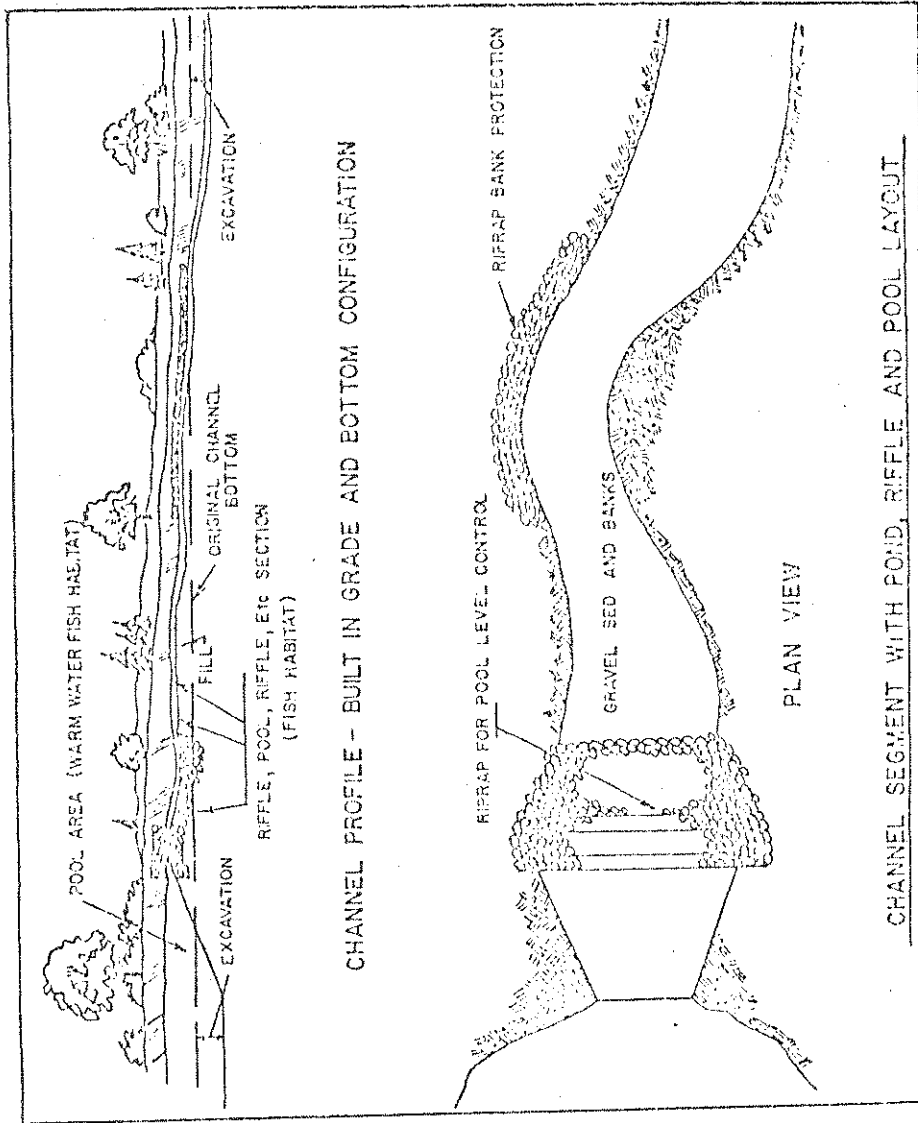


Figure 30 Idealized diagram illustrating the fabrication of pools and riffles.
 (after SCS, 1971)

It appears, therefore, that these velocity conditions prevail only during low flow, and undergo a velocity reversal in periods of high flow. That is, in high flow conditions, relative velocities reverse, with higher velocities in pools that scour the bed. In diverging riffle sections at high flow, velocities are relatively lower, and deposition results. Construction of artificial pool-riffle sequences is desirable, but the use of convergent - divergent flow conditions should be applied to make such structures self-perpetuating.

The Soil Conservation Service has also advocated the modification of only one bankline. Although the principle is good, in practice the method has been just as effective in upsetting natural conditions. This type of project has been used in conjunction with construction of a separate flood-flow channel which, if properly planned, could be of great benefit in times of flood, while leaving the low flow stream essentially unchanged. This would be analogous to the construction of a series of meander cutoffs; however, the cutoffs would be at a level that is functional only during flood stage.

Soil Conservation Service plans also call for impoundment structures that would be utilized to contain flood waters until peak flows had passed from the basin; these impoundments could also serve to partially retain supplies to be used as recharge for ground water reserves. Careful consideration of such structures should be undertaken, as they

would involve considerable added cost and maintenance problems.

River Training

River training techniques have been used with considerable success on the larger rivers of the world, for example in Europe on the Garonne and the Rhine, and in the United States on the Missouri and the Mississippi. Such training is accomplished by strategic placing of permeable pile-dike structures, so as to use natural fluvial processes to develop and maintain a stable channel. The intent of the pile structures is to slow velocities, and initiate deposition, thus soon forming semi-permanent point bars or channel-islands. This process tends to converge flow into one main channel and scour it to a deeper level.

River training has been used primarily for purposes of navigation, converting a shallow, semi-braided river to a single, narrower, much deeper channel suitable for additional and larger barge traffic. It is unfortunate that such methods have never been applied to smaller-scale streams, as it is anticipated that equally successful results might be obtained at this scale. Limited use of pile structures in conjunction with channel modification programs could reduce or prevent bank stability problems in erosion-prone areas. If such areas could be delineated prior to construction, the use of asymmetric channel cross-sections could also induce deposition.

modification the stream will tolerate without causing channel instability.

6) Straight stream reaches are stable only at very low slopes. In channelization design, gradient increase should not accompany channel straightening.

The following recommendations result from the conclusions reached in this study. It is anticipated that the application of these will allow improved drainage and channel stability with limited additional problems and environmental degradation.

RECOMMENDATIONS for APPLICATION

- 1) Determine the proper design that should be used. Don't hesitate to apply new concepts such as thresholds in design criteria. Use new designs that cause less environmental degradation.
- 2) Determine the runoff hydrograph of the proposed modified stream to see if downstream reaches can accommodate increased peak flows.
- 3) Coordinate projects with other channelization or modification projects within the drainage basin, to provide a complete and integrated drainage network.
- 4) Use soil stabilization methods in conjunction with channel modification: i.e., sediment settling basins, vegetative stabilization (crown vetch, jute netting, contour plowing, row cropping, grassed waterway swales), etc.
- 5) Keep tall vegetation out of waterway channels. Trees

and bushes within the channel may cut its capacity by 60 percent.

RECOMMENDATIONS for FURTHER RESEARCH

- 1) Further research as to the effects on fish and wildlife seems to be necessary. Unfortunately, environmental groups slant evidence against channelization, whereas the SCS and other soil-water conservation agencies tend to glorify the results of their projects. The need for unbiased research and results, such as that presented in this report, will remain until a viable solution to the problems of channelization is attained.
- 2) Concepts such as fluvial thresholds as presented in this report should be tested on large-scale channelization projects. With the cooperation of agencies such as the Corps of Engineers, data from such projects could easily be obtained.
- 3) The study of channelized streams that do not appear to be reverting back to a more natural state might provide the answers to many of the problems presented here. If such streams do exist, it seems essential that they also should be studied.

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